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LIFE HISTORIES OF COMMON PLANTS

BY

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PREFACE.

THIS book is intended as an introduction to the study of Plant Life by continuous outdoor and indoor observation and experiment. It differs considerably in scope and treatment from the recently published *Plant Biology*,* but, like that work, is based largely upon the courses in Elementary Botany which I have organised and conducted for several years in classes consisting chiefly of Day Training College students.

In the Elementary Botany Course given in this College the number of students is so large (over a hundred each session) that, in order to make the course thoroughly practical, the students are taken in seven sections each week. In no other way has it been found possible to do satisfactory work: each class must be small, so that each student may make observations and experiments under proper guidance and supervision. Since we have, of course, classes in advanced Botany, as well as in Zoology and Geology, the division of the Elementary Botany Course into so many sections, involving the repetition of each lesson, makes the work very laborious. However, I am firmly convinced that the elements of Plant Biology can only be taught successfully by discarding formal lectures, by giving the foremost place to Physiology

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and Ecology, and by insisting upon actual observations, experiments, and the making of notes and sketches by each student. The many letters I have received from former students who have followed up their work in Plant Biology after leaving college and taking up teaching, and who have applied the same practical methods in their classes of school-children, have encouraged me in continuing to conduct these College classes on the lines indicated.

In this book I have borne specially in mind the needs of the student who is working alone, as well as those of practising teachers. I fear that in too many instances I have erred on the side of giving too much information, but on the whole I have tried to write the book in such a way as to *make* the student set about getting the plants and examining them at first hand. I have throughout the book emphasised the importance of continuous outdoor and indoor observations and experiments, raising questions which can only be answered by honest personal research. Above all, I have endeavoured to defeat the unworthy aims of the misguided type of student—too familiar to all earnest and energetic science instructors—who, taking no real interest in science and possibly taking it up from necessity rather than choice, merely wishes to cram or be crammed with ready-digested knowledge. For such idle and unenterprising students there are many suitable books—books which may serve to while away the time, afford easy and more or less interesting arm-chair reading, and possibly float the student up to the high-water mark of an examination pass. I have collected and waded through as much “Nature Study” literature as possible, but I must confess that I regard most of it—apart from its general slipshod and inaccurate character—as bearing somewhat the same relation to the few real live enquiry-provoking books on the subject that the “penny dreadful” bears to good fiction. I would, however, strongly recommend the use of such excellent books as Professor Miall’s *Round the Year* and *House, Field, and Garden*,

Scott-Elliot's *Nature Studies (Plant Life)*, and Osterhaut's *Experiments with Plants*. Professor Welton's *Principles and Methods of Teaching* (Clive, 4/6) contains an excellent chapter on the teaching of Natural History, especially Plant-life.

This book is intended merely as an introduction to Botany, but I am convinced that the student who works faithfully through it, and carries out all the observations and experiments, will, if imbued with the spirit of inquiry and research, have laid a solid foundation for a sound acquaintance with the structure and life-processes of plants, and the relations of plants to their surroundings. There can be no excuse for a student of Plant Life who neglects to carry out such simple observations and experiments as those for which directions are given in this book. In most cases the necessary materials and apparatus can easily be obtained at a cost so trifling as to place them within the reach of all.

In the case of beginners there should be no attempt to acquire an extensive acquaintance with the descriptive terms used in Floras, nor with the characters of Natural Orders. Later on the use of a Flora and perhaps even that of schedules or other set forms for plant-description is to be recommended (I would never use these schedules myself in elementary classes), so long as the Biology, especially the Physiology and Ecology, of plants is kept to the fore. The plant is best regarded as a machine, the parts of which perform different functions, the form and structure of each part being adapted for the special work it has to do. The study of the form and structure of plants, without reference to the functions and adaptations of the various parts, is comparatively barren and useless so far as educational requirements are concerned. Work through as much as possible of this book, get to know the commoner plants met with in their homes or "habitats," and use common sense in applying the facts of Plant-physiology and Plant-structure to the explanation of the various adaptations of plants to their surroundings.

Perhaps the best beginning one can make in the study of Plant Life is to examine any common plant thoroughly, experiment with it, and follow out as much as possible of its life-history. To do this thoroughly and exhaustively would, needless to say, mean years of laborious research; but probably none except a relatively small number of the lower plants have ever been dealt with in this way. The whole of this book would barely suffice to contain a detailed account of the structure and physiology of any one of the plants mentioned in it.

I have not included much microscopic work, but in the classes referred to we have found that simple work on the microscopic structure of roots, stems, leaves, pollen-tubes, etc., has proved a useful sequel to naked-eye and lens work. The provision of a compound microscope for each student would be, of course, neither practicable nor advisable in large classes of young students, but, though much good work in Plant Biology can be done without one, every teacher and serious student of this subject should get a cheap instrument, costing about £5, which will answer quite well.

This book has been prepared, in the first instance, to meet the requirements of candidates for the Certificate and Preliminary Certificate Examinations of the Board of Education. Preliminary Certificate Candidates may omit the following articles:—90 to 94, 96 to 99, 101 to 105, 190, 191, 246 to 249, 251, 256, 257, 261 to 265, 268, 270 to 272, 278, 279, 281, 282, 290 to 292, 310, 312 to 317.

I shall be very glad to receive suggestions or criticisms from teachers or others who use this book.

F. CAVERS.

HARTLEY UNIVERSITY COLLEGE,
SOUTHAMPTON.

June 20, 1908.

CONTENTS.

CHAPTER I.

THE BROAD BEAN PLANT.

	PAGE
Practical work ; sketches ; hints on lens work ; the Broad Bean	1
The root ; arrangement and origin of rootlets ; root-hairs ; root-cap ; root-nodules	4
The shoot ; air-spaces in shoot	6
The leaf ; arrangement ; leaflet ; stipules ; leaf-stalk	7
Branches and buds	9
The flowers ; calyx, corolla, stamen, pistil	9
The fruit ; seed ; seed-coat, micropyle, seed-lobes, etc.	12
The seedling ; seedling compared with seed, and with mature plant	14
QUESTIONS ON CHAPTER I.	16

CHAPTER II.

SEEDS AND SEEDLINGS.

The germination of the seed ; germination jars ; glass-sided boxes	18
Early stages of germination	20
Water required for germination	22
Amount of water absorbed by seeds ; where and how water enters the seed ; capillarity and osmosis	23
Is air required for germination ?	25
The atmosphere ; oxygen ; nitrogen ; carbon dioxide and water-vapour in air	25
Respiration of germinating seeds ; heat produced by respiration	27
Conditions essential for germination	31
Growth in light and in darkness ; growth in soil and in sawdust	31
Food contained in Bean seed	32
Carbohydrates ; proteids ; oils	34
Digestion of reserve foods	37

	PAGE
How long the seed's food lasts ; how foods are transported ...	40
Emergence of seedlings from soil	42
Other seeds and seedlings	42
French Bean and Scarlet Runner	43
Garden Pea and Sweet Pea	44
Oak	44
Sycamore	46
Sunflower	47
Maize	48
Wheat	52
Further work on seeds and seedlings	52
Seeds with food stored in cotyledons... ..	53
Endospermic seeds	53
The uses of cotyledons	56
QUESTIONS ON CHAPTER II.	56

CHAPTER III.

THE GREEN PLANT'S NUTRITION.

Questions arising from work on seedlings	59
Chief functions of root and shoot	59
Effects of removing cotyledons and foliage-leaves	61
Comparison of cotyledons and foliage-leaves	61
Do leaves contain food? does the green leaf make starch? ...	62
Is light required for starch-making?	63
Is air needed for starch-making?	64
Is chlorophyll needed for starch-making?	65
How does starch disappear in darkness?	66
How is air concerned in starch-making?	67
How is the volume of the air affected? how is its composition affected?	68
How is starch made by the green leaf?	70
Chlorophyll; under what conditions is it produced and what is its function?	70
Food-materials of a green plant; essential elements of plant-food	73
Water-culture experiments	74
Essential soil-substances; nitrates	76
Formation of nitrogenous substance and of proteids	76
The main function of the green leaf	77

Respiration ; the "balance of nature"	78
Structure of the leaf	81
Transpiration	84
Root-hairs ; root-pressure	89
Adaptation of green leaf to its functions	91
Forms of leaves ; stipules ; petiole ; veins	92
Simple and compound leaves ; leaf-arrangement ; leaf-mosaics ; how leaves are protected	94
Decay and fall of leaf	99
QUESTIONS ON CHAPTER III.	100

CHAPTER IV.

THE GROWTH OF SHOOT AND ROOT.

How to measure growth in length of root and stem ; where does growth in length occur ?	103
How the young root enters the soil ; force exerted in pushing downwards	104
What makes root grow downwards and stem upwards ?	105
How do moisture, light, and contact affect direction of growth ? ...	106
The root-tip a sensitive organ ; clinostat	108
Regions of the root ; how the root-tip is protected	111
Conducting channels of stem	112
Chief functions of stem	114
Structure of stem and of root	115
Growth in thickness ; annual rings of wood ; rays ; heart-wood and sap-wood ; knots ; cambium ; cork and bark ; lenticels ; practical work on woody stems	118
QUESTIONS ON CHAPTER IV.	123

CHAPTER V.

BUDS.

Buds ; winter buds (resting-buds) ; Brussels Sprout	127
Sycamore	131
Horse Chestnut	133
Oak	135
Scots Pine	136
Larch	137
QUESTIONS ON CHAPTER V.	138

CHAPTER VI.

FLOWERS, FRUITS, AND SEEDS.

PAGE

The work of the flower ; pollination and fertilisation ; self-pollination and cross-pollination	140
Mechanism and attractions of Broad Bean flower	144
The calyx and its functions	146
The corolla and its functions	147
The andrecium and the gynecium	148
Inflorescences—racemose, cymose, mixed, compound	151
Contrivances and conditions favouring cross-pollination ; protandry ; protogyny ; heterostyly ; special arrangements for self-pollination	153
Insects that visit flowers	156
Flowers adapted for short-tongued insects	157
Flowers with partially and with fully concealed honey	160
Long-tubed flowers ; butterfly- and moth-flowers	161
The flower-tube ; protection against rain	163
Wind-pollinated flowers ; Willows and Poplars compared ; Fagales ; Pine, Larch, Yew ; Dog's Mercury ; Plantain	163
How fruits are formed ; capsular fruits ; akenial fruits ; fleshy fruits (drupes, berries, pomes) ; aggregate fruits ; special types	167
Dispersal of seeds and fruits by wind, water, animals ; censer-mechanisms ; explosive fruits	174
Seeds ; practical work on fruits and seed-dispersal	178
QUESTIONS ON CHAPTER VI.	179

CHAPTER VII.

SWEET PEA, VETCHES, CLOVERS, SCARLET RUNNER,
GORSE, LABURNUM.

The study of typical plants	182
Trees and shrubs... ..	183
Sweet Pea ; Everlasting Pea ; Yellow Vetchling ; Grass Vetch ; Garden Pea	184
Vetches : Tare, Tufted Vetch, Bush Vetch	187
White or Dutch Clover ; Red Clover	188
Scarlet Runner	193

CONTENTS.

xiii

PAGE

Common Gorse ; Dwarf Gorse	198
Laburnum ; Broom	202
The Bean Family ; flower-mechanisms	203
Leguminous root-nodules ; nitrogen-fixing Bacteria	204
QUESTIONS ON CHAPTER VII.	205

CHAPTER VIII.

CELANDINE, BUTTERCUPS, WATER CROWFOOT, MARSH MARIGOLD.

Little Celandine	208
Buttercups ; Spearworts	210
Water Crowfoot	212
Marsh Marigold	213
Water and Marsh Plants	214
The Buttercup Family	217
Classification (Varieties, Species, Genera, Orders, Cohorts)	218
QUESTIONS ON CHAPTER VIII.	219

CHAPTER IX.

DOG ROSE, STRAWBERRY, HAWTHORN, ROWAN.

Dog Rose ; other wild Roses	221
Strawberry ; Wild Strawberry ; Barren Strawberry and other Potentillas	224
Hawthorn ; thorns and prickles	225
Rowan (Mountain Ash)	227
Rose Family	228
QUESTIONS ON CHAPTER IX.	229

CHAPTER X.

VIOLETS, PANSIES, WOOD SORREL, IVY.

Violets : Sweet Violet, Dog Violet	231
Pansies	235
Wood Sorrel	237
Ivy	240
QUESTIONS ON CHAPTER X.	242

CHAPTER XI.

LING, HEATHS, BILBERRY, CROWBERRY.

	PAGE
Ling (Heather)	244
Bell Heath	245
Cross-leaved Heath	245
Bilberry	246
Crowberry	247
Moorland and Bog Plants	247
QUESTIONS ON CHAPTER XI.	250

CHAPTER XII.

PRIMROSE AND COWSLIP.

Primrose	251
Cowslip	253
Pollination of Primrose and Cowslip	254
QUESTIONS ON CHAPTER XII.	256

CHAPTER XIII.

POTATO, BITTERSWEET, GOOSE-GRASS.

Potato	257
Bittersweet; Black Solanum	261
Goosegrass	262
QUESTIONS ON CHAPTER XIII.	264

CHAPTER XIV.

DANDELION, DAISY, COLTSFOOT.

Dandelion	265
Daisy	270
Coltsfoot	272
The Composite Family	273
QUESTIONS ON CHAPTER XIV.	274

CHAPTER XV.

CROCUS, BLUEBELL, EARLY PURPLE ORCHID.

Crocus	276
Bluebell; Garden Hyacinth; Daffodil; Onion	283
Early Purple Orchid	285
Note on spring-flowering plants	290
QUESTIONS ON CHAPTER XV.	291

CHAPTER XVI.

WHEAT, OAT, BRITISH GRASSES.

	PAGE
Wheat	293
Oat	297
The Grass Family	298
Classification of British Grasses	301
Notes on British Grasses	303
QUESTIONS ON CHAPTER XVI.	305

CHAPTER XVII.

POPLARS AND WILLOWS.

Black Poplar	307
Lombardy Poplar ; Aspen ; White Poplar	309
Willows	310
Narrow-leaved Willows : Crack Willow ; French Willow ; White Willow ; Osiers	311
Broad-leaved Willows : Goat Willow ; Round-eared Willow ; Grey Sallow ; Bay-leaved Willow ; Dwarf Willows	312
QUESTIONS ON CHAPTER XVII.	312

CHAPTER XVIII.

ALDER, HAZEL, BIRCH, OAK, BEECH.

Alder	313
Hazel	314
Birch	317
Oak ; Turkey Oak ; Evergreen Oak ; Cork Oak	319
Beech	321
QUESTIONS ON CHAPTER XVIII.	323

CHAPTER XIX.

ELM, SYCAMORE, HORSE CHESTNUT, LILAC, ASH.

Elm : Wych Elm ; Common Elm	325
Sycamore ; Field Maple ; Norway Maple ; Ash-leaved Maple	327
Horse Chestnut ; Buckeye ; Red Horse Chestnut	329
Common Lilac ; Persian, Josika's, and Rouen Lilacs	331
Common Ash ; Manna Ash	332
QUESTIONS ON CHAPTER XIX.	334

CHAPTER XX.

PINES, LARCH, FIRS, YEW, JUNIPER.

	PAGE
Scots Pine	335
Austrian Pine ; Stone Pine ; Cluster Pine ; Weymouth Pine ...	337
Larch ; Cedars	337
Spruce Fir ; Silver Fir ; Douglas Fir	339
Native British Conifers ; Yew ; Juniper	339
QUESTIONS ON CHAPTER XX.	340

CHAPTER XXI.

THE ECOLOGY OF PLANTS.

Plant Ecology ; terms used in Ecology	341
Geographical distribution of plants	343
The Environment : temperature ; moisture ; light ; substratum ...	344
Humus-plants ; chalk-plants ; clay-plants ; sand-plants	346
Strand-plants ; salt-marshes	348
Woods and plantations ; hedges	350
Adaptation ; the plant's equipment	351
Field observations	353
The Grass type ; the arborescent type	354
Conclusion	355
QUESTIONS ON CHAPTER XXI.	356
INDEX	358

LIFE HISTORIES OF COMMON PLANTS.

CHAPTER I.

THE BROAD BEAN PLANT.

1. A good way in which to begin work on plant-life is to raise plants from seed. The chief reason why the Broad Bean has been chosen for our first studies is that its seeds are easily germinated at any time of year, yielding in a short time vigorous young plants which serve admirably for practical work on plant-structure and plant-physiology. Flowering and fruiting plants can be obtained throughout the summer months; in winter one must, of course, use seedlings raised indoors.

Before proceeding further, a few hints are offered for the benefit of those who are about to begin the study of plant-life.

2. Practical Work.—Get all the seeds, plants, and other materials mentioned in the directions for practical work and carry out the directions faithfully, making observations and experiments for yourself and keeping a careful record of your work written in your own words and illustrated by your own drawings from actual objects. All the plants mentioned are easily obtained, at very little cost—none at all in the case of wild plants—and there can be no excuse for remaining content with a second-hand smattering gained by mere reading when with a little trouble you can get some real knowledge.

3. Sketches Required.—It is of the utmost importance that, besides keeping a written record of all your observations and experiments, you should make careful drawings of all specimens you examine. Use a note-book of unruled paper (not too thin); if you write your notes in the same book, keep notes and sketches on separate pages; make your sketches large (natural size or, in most cases, enlarged) and clear (no shading, no superfluous or meaningless marks or lines, and no “inking-in” afterwards). Measure the specimens you are going to draw, record the measurements, and if enlargement is necessary in order to show details clearly, draw to a definite scale and note how many times your sketch is magnified ($\times 2$, $\times 3$, etc.). All the parts shown should be labelled; do not write the names inside the drawing, but at the end of a line drawn to the part named. Do not leave your sketches like nameless islands; write below each the name of the plant, the part of the plant, the aspect represented, etc.

4. Hints on Lens Work.—So much can be done with a lens, especially if a microscope is not available, that some hints on lens work may be useful. The best kind of lens is the “aplanatic” or “platyscopic,” which gives a flat field of vision without distortion of the edges; but a triple folding-lens will do, and is much cheaper. It is easy to make a simple stand to carry the lens, and to allow of both hands being used in dissecting the specimen examined. The lens can be fixed to a cork which slides up and down a vertical rod, e.g. a knitting-needle or hat-pin, inserted into a wooden base. Another plan, much simpler, is to use a watchmaker’s lens, worn in the same way as a monocle. Another useful plan is to get a piece of thick glass, about 9 by 4 ins.; to one side of it paste two pieces of thick paper, each 3 by 4 ins., one black, the other white (or a single piece, 6 by 4 ins., with one half painted black). Keep the papered side downwards, placing on the upper side the objects to be examined with the lens; move them along so as to see their appearance against the opaque white and black surfaces, and also against the light through the transparent part of the plate.

5. The Broad Bean is distinguished from other “Bean-plants” (French or Kidney Bean, Scarlet Runner) by its erect mode of growth, its square stem, its leaves with large stipules and from four to seven oval leaflets, its white flowers with a black blotch on each lateral petal (Fig. 1). It is commonly cultivated for its large edible seeds, and (like most cultivated plants) shows several varieties (Longpod,

Mazagan, etc.), differing in such details as shape and size of pod and seed and in times of flowering. A common and distinct variety is the Field or Horse Bean, of which the seeds

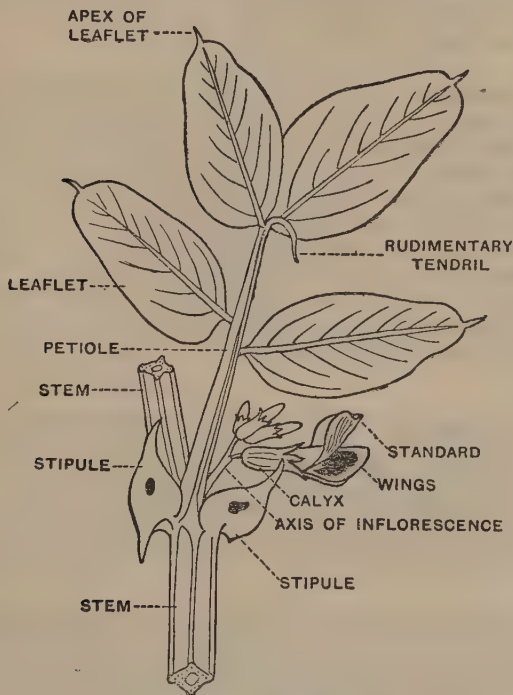


Fig. 1.—Part of a Broad Bean Plant

are used chiefly for feeding horses, the “straw” for stabling purposes; its seeds are much smaller and less flattened than those of the typical Windsor Broad Bean.

6. Dig up an entire Broad Bean plant in the garden (or the very similar Horse Bean grown in the fields), and free the root from the soil that clings to it by shaking it to and fro in a pailful of water and afterwards washing under a stream of water from a tap. Set the plant in a

basin of clean water, so as to allow the branching root to spread out, as well as to prevent its drying up.

If complete flowering and fruiting Broad Bean plants cannot be obtained at once, begin by studying the seed and its germination (Art. 29 and rest of this chapter; Ch. II.). Make successive sowings in the garden,* also in pots and boxes, so as to get abundant material, in the form of seedlings, to start work with.

7. The Root consists of a main downward-growing axis (continuous with the upward-growing axis or stem), from which arise branches that spread out from it. Are these first branches horizontal or not? Do they all make the same angle with the main root? These first branches give rise in their turn to finer branches; in what directions do *these* grow in the soil, and how many times may the process of branching be repeated? Compare the different directions of growth taken by the main axis and by the successive sets of branches. How do these differences help the root to come into contact with as much soil-space as possible in the most economical way?

8. Arrangement of Rootlets.—Are the first branches scattered over the surface of the main root? To make out their arrangement, cut out a straight piece of main root, about 6 ins. long, cut off the branches about an inch from their origin, and look along the piece from end to end. Sketch the piece, showing the rows of branches arranged along the axis.† How many rows are there? Does the arrangement in longitudinal rows extend to the further branchings of the root?

9. Origin of Rootlets.—Examine closely the place where a branch (rootlet) leaves the parent-root. Is the surface smooth and continuous, or is there anything visible that suggests the way in which the branch arose from the parent-root? What further information is gained by cutting across the parent-root at this point with a sharp knife or a razor, and examining with a lens the cut surface? In what

* Messrs. Toogood and Son, Southampton, will send post free for 1s. two excellent gardening books—*Culture of Vegetables* and *Culture of Flowers*.

† This arrangement can easily be made out in seedlings. In the Broad Bean the side-roots are usually in 5 rows on the main root (Fig. 10); in the Scarlet Runner and the French Bean there are usually 4 rows, arranged with great regularity on the main root (Fig. 18).

region of the main root are the branches shortest and thinnest? Look for young branches just emerging from the parent-root; in what direction do they grow at first? (See Fig. 2.)

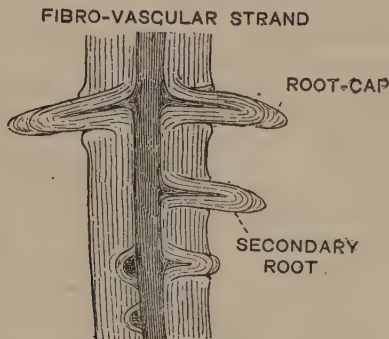


Fig. 2.—Longitudinal Section through Primary Root, showing Origin of Secondary Roots from Central Vascular Cylinder.

10. Root-Tip.—Note the gradual tapering of the axis and of the rootlets towards their free ends, and the softness and whiteness of the latter as compared with the older parts. Cut off the ends of some of the rootlets, about an inch behind the extreme tip, place them in a drop of water on a glass slide, and examine them with the lens; try holding the slide (1) against the light, (2) over a white surface, (3) over a black surface.

11. Root-Hairs.—Look for very fine threads, which will be found behind the root-tip, if the latter has not been damaged. These are the root-hairs, to which small particles of soil may still be sticking. Root-hairs are more easily seen in seedlings (Ch. II.). They previously existed on the older parts of the root, but they disappear as the root grows, while new hairs are continually being formed just behind the growing extremity of the rootlet.

12. Root-Cap.—At the end of each rootlet, note the more transparent conical mass at the extreme tip, separated from the denser main body of the rootlet by a curved outline. This conical mass is the root-cap; it is thickest at the tip and extends a little distance at the sides, fitting over the end of the rootlet like a thimble on a finger.

Root-hairs and root-cap can be more easily examined in a seedling; these structures are often damaged in removing the mature plant from the soil.

13. Root-Nodules.—Note, here and there on the main root and the rootlets, little wart-like swellings, varying in size and shape. These swellings (nodules or tubercles) are characteristic of the roots of Beans, Peas, Clover, and allied plants (see Ch. VII., Art. 253).

14. The Shoot.—The whole of the upper part of the bean-plant, above the ground, may be called the *shoot*, as distinguished from the root, which grows in the soil. In passing from the downward-growing axis or root to the upward-growing axis or stem, what changes do you notice in (a) shape of axis, (b) colour of axis, (c) nature of appendages carried by the axis? Note the four flat sides of the stem, and its green colour, often tinged with red. We saw that the root consists of a main cylindrical axis which is covered at the tip by a root-cap and which bears as appendages (a) root-hairs, (b) root-nodules, (c) rootlets which repeat the form of the main axis and bear the same appendages. What are the appendages of the shoot-axis (stem)? (a) Some of these consist of a stalk which is grooved on its upper surface, carries a number of thin flat outgrowths on either side, and (usually) ends in a slender prolongation. (b) Other appendages of the stem consist of a four-sided stalk which carries appendages like (a), and which therefore repeats the form of the main stem itself and may be called a *branch* of the stem, just as a rootlet is a branch of the root. In many plants, e.g. Wallflower, the first kind of stem-appendage consists of an undivided thin flat piece; such an appendage is called a *simple leaf*. The corresponding appendage of the Bean is also a leaf, but here the leaf is not simple, as in the Wallflower, but *compound*, its thin flat portion being divided into several pieces, the *leaflets*.

15. Air-Spaces in Shoot.—You have noticed a central cavity in some of the cross-sections. How far does this cavity extend in the stem, and is it continuous? Find out by slitting up the whole stem from top to bottom. Does it run out into the branches and the leaves? What does it contain in the uninjured living stem? Lay a whole plant in a basin, cover it with cold water, and cut across the stem and the branches at several places: what do you notice escaping from the cut ends? Is this central cavity the only part that contains air? Take the plant out, replace the cold water by hot water (just boiled), and notice what happens when you place in it (a) a piece of stem only, with the cut ends previously well plugged with plasticine,

(b) a whole plant. The results of these simple experiments show that the whole shoot contains air-spaces and that these communicate with the atmosphere by openings scattered over the surface. From the number of bubbles seen to escape, the leaves evidently have more air-openings than the stem. Which side of a leaflet, upper or lower, seems to have most openings? These air-openings are called *stomates*.

16. The Leaf.—Each leaf consists of an axis (leaf-stalk) which bears right and left a number of thin flat outgrowths. The two lowest of these lie on each side at the base of the leaf-stalk, close to the stem; they are called *stipules*, to distinguish them from the leaflets carried higher up on the stalk. The leaflets are rather variable in number, but we usually find a pair close together, right and left, near the top of the stalk, and from two to four spaced out on the stalk below these. Note the difference in shape between the leaflets (oval) and the stipules (triangular, like one lateral half of a spear-head); what other differences do they show? Notice the slender outgrowth into which the leaf-stalk is (usually) prolonged above the leaflets (Fig. 1). Do any of the leaves in your plants bear a leaflet in place of this outgrowth, and do you find any leaves ending in structures intermediate between these two extremes? Note that the leaf-stalk comes off at one of the ridges of the stem, the stipules being against the two adjacent flat sides of the stem.

17. Arrangement of Leaves.—Follow the ridges along the stem, and find out in how many rows the leaves are arranged. Do leaves come off at all four ridges? Do the ridges run straight up and down the stem, or is there any twisting? Compare the leaf-arrangement in the Broad Bean with that observed in other plants which have square stems—*e.g.* White or Red Dead-nettle, Mint, Figwort, Coleus—and note any differences.

18. The Leaflet.—Notice the chief vein (midrib), which runs through the leaflet from the base to the tip. What do you notice at the tip? Note the branch-veins arising on each side from the midrib, the finer veins arising from these, and the delicate net-like arrangement of the still finer veins (hold the leaflet against the light). What differences do you notice between the upper and lower surfaces of the leaflet? Notice that the chief veins appear as grooves on one surface (which?) and as projections on the other.

Hold the leaflet, with the lower surface towards you, between the thumb and forefinger of each hand, and, starting from a point on one edge, tear the leaflet across. Notice the thin colourless skin

which can be torn off in this way, and the green inner tissue which is exposed; small specks of the green tissue remain attached to the skin, unless the tearing is done very carefully (try it several times, starting at different points on the edge of the leaflet). Now try to tear off the upper skin in the same way, and notice that it also is colourless, though a good deal of the green tissue always comes away with it. The leaflet therefore consists of a thin colourless skin covering its upper and lower surfaces, and a thick middle green tissue which is denser towards the upper surface and looser towards the lower surface (how is this inferred from your tearing experiments?) and which contains the veins.

19. "Bloom" on Leaf-surface.—Dip a leaflet into water and notice, on lifting it out, that the water runs off the surface very quickly, leaving it dry. Lay a leaflet on the table and place a drop of water on either surface in turn: notice in both cases that the water forms a globule instead of spreading over the surface. This shows that the leaf is not easily wetted by water, and suggests that the surface is covered by some substance like wax. This waxy substance is similar to that which forms the "bloom" on Grapes, Plums, etc., so that one might say the Broad Bean leaflet is covered with "bloom," which prevents water from wetting it and reaching the inner tissue. Try to remove the bloom by rubbing the leaflet gently (1) with a dry cloth, (2) with a cloth dipped into warm water; water placed on the leaflet will then wet the surface and spread over it.

20. The Stipules.—How does a stipule differ from a leaflet in shape, colour, and texture? Has it any veins (hold it against the light)? Notice the patch near the centre of the stipule; at first it is bright red or violet in colour, later it becomes brown or black. On which surface of the stipule is this patch most easily seen? This patch consists of minute glandular hairs, very closely crowded together on the lower surface of the stipule. A similar patch of glands occurs on the stipule in the Common Vetch of fields (*Vicia sativa*), the nearest ally of the Broad Bean among British plants; its functions are doubtful.

21. The Leaf-Stalk (Petiole).—Note the groove on the upper surface, making the leaf-stalk gutter-shaped. What does this comparison with a gutter suggest as to the use of the groove in wet weather? Test the matter by a simple experiment with a watering-pot, or watch a plant during a shower of rain. Does this suggest also the use of the little pointed tip at the end of each leaflet? What about the narrow prolonged tip at the end of the leaf-stalk? The nearest relatives of the Broad Bean are the Vetches and Peas, which differ from our type in being weak-stemmed climbing plants. Get any of these (e.g. Sweet Peas) and compare their leaves with that of the Broad Bean. What light does the comparison throw on the nature of this part of the Broad Bean leaf? A special organ used for climbing is called a *tendrill*. Make out with the lens the structure of

the leaf-stalk. How are the bundles arranged? Is there a central air-channel, and is it continuous with the air-channel of the stem, or the branch, that bears the leaf?

22. Branches and Buds.—You will have noticed that each branch of the stem arises just above the base of a leaf, and that as a rule they become shorter towards the upper end of the stem. Pull off the young leaves at the end of the stem or of a branch, to see the small young branches (*buds*), one above the base of each leaf. These buds are called *axillary*, the space between the leaf-base and the part of the stem above it being called the *axil* of the leaf. At the very end of the main stem and of each branch there is a *terminal bud*. A bud is simply a young shoot, consisting of a short axis (stem) bearing young leaves which are closely crowded together and overlap the growing apex of the axis. Later on, the stem part of the bud grows in length and the leaves become spaced out on it, as well as growing larger.

The points on the stem where leaves come off are called *nodes*, the parts between the nodes being called *internodes*; but these names, though useful in describing plants, are often associated with a false conception of the shoot as being made up of "joints," each consisting of an internode and a node bearing one or more leaves. The node is merely a place where a leaf stands on the stem, and where the bundles of the stem divide and join with those of the leaf and also with each other, causing a swelling.

23. The Flowers* of the Broad Bean are arranged in small clusters, each cluster arising in the axil of a leaf, and each flower is attached by a short stalk to the axis of the cluster, which occupies the same position on the shoot as an ordinary branch. The cluster or flower-bearing branch is called an inflorescence. Turn down or pull off the leaf just below an *inflorescence*, and examine the latter closely. This special kind of inflorescence, with the individual flowers stalked and spaced out on the axis, is called a *raceme*; the youngest flowers are nearest the top.

* If Broad Bean flowers are not available, use those of Sweet Pea.

Note the parts of a single flower (Figs. 3, 4), starting from the outside :—

24.* The Calyx, a greenish or colourless cup, with its free edge produced into five pointed lobes. Note the veins which start from the bottom of the cup, one running up the middle of each lobe, others between the lobes.

25. The Corolla, consisting apparently of four pieces, a large upper piece (*standard*), two smaller side pieces (*wings*), and a lower boat-shaped piece (*keel*). Note the way in which the standard is folded below over the wings, which in turn enfold the keel. The standard is on the upper (posterior) side of the flower, i.e. the side towards the axis of the inflorescence ; note the position of each of the

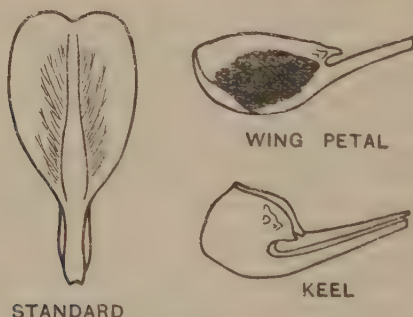


Fig. 3.—Corolla of Broad Bean.

calyx-lobes with reference to the axis, the odd one being the lowest. Open the calyx by cutting or tearing it between the two upper lobes, to see the exact shape and position of each of the four parts of the corolla. Remove the standard and sketch it (front surface and side view) ; note its broad upper part, marked by coloured streaks, and the narrow lower part by which it is attached to the *receptacle* (i.e. the expanded upper end of the flower-stalk, to which all the parts of the flowers are attached). In each wing note the narrow stalk, and the broad oval portion which has a large blackish spot. Gently pull each wing outwards, and note that it clings to the outer surface of the keel : can it be pulled off without tearing anything ? Note the way in which the wing on each side is locked with the keel ; at this place the wing

* In dissecting flowers use a sharp penknife (a pair of fine scissors will also be useful), a pair of forceps for seizing the parts of the flower, and a lens.

and the keel show a series of folds, the corrugated surfaces fitting together. Remove and sketch one of the wings, both from inner side and outer side. In removing the standard and the wings, note that these pieces (*petals*) alternate in position with the calyx-lobes, *i.e.* the insertion of each of these three petals is just inside the space between two of the calyx-lobes. Now examine the keel, and note that it is carried on two separate stalks; detach these at their bases and pull them apart, when the keel will split along its sharp lower edge into two pieces. The corolla, then, consists in reality of five petals, the two lowest being attached to each other to form the keel, and the five petals alternate in position with the five *sepals* (calyx-lobes).

26. The Stamens (Fig. 4).—On opening up the keel you will see a number of small oval bodies (*anthers*), each carried at the end of a thin stalk (*filament*). How many anthers are there? If you see any stalks bare at the end, try another flower (a young unopened flower is best). Trace the stalks down, and notice that most of them are joined below to a thin colourless plate which is folded longitudinally. Does this folded plate form a complete tube or is it open? Where is the opening, and how is it covered over? Are any of the filaments free from the folded plate? Each anther, with its filament, constitutes a *stamen*, but only the uppermost stamen is free right down to the flower-axis; the others arise from the “stamen-trough.” The upper parts of all the stamens bend sharply upwards, to suit the shape of the keel, in which they are enclosed; there is a narrow opening along the upper side of the keel, above the free stamen. Examine an anther with the lens, noting the two lobes divided by a longitudinal groove, and each showing a less marked groove; the anther consists of four *pollen-sacs* lying side by side. This can only be seen in a young flower; in an older one the anther will have opened by two slits, one at each side, allowing the yellow dust-like *pollen* to escape. Sketch the ten stamens, with the “stamen-trough” as seen from the side; then cut round the base of the trough, remove it, and sketch it spread out.

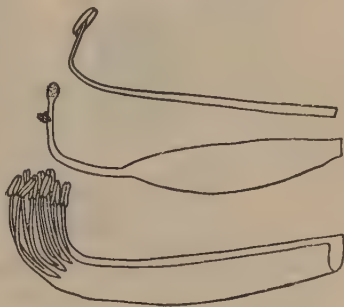


Fig. 4.—Stamens and Pistil of Broad Bean.

27. The Pistil (Fig. 4), the innermost part of the flower, is now seen. It consists of a long green lower part with flattened sides, and a tapering free end produced into a slender outgrowth (*style*), which bends upwards and bears a tuft of hairs on the lower side of the bend, just below the tip. Examine these parts carefully, and sketch the whole

pistil in side view. The lower part of the pistil resembles a small bean-pod, and for the present we may call it the "young pod." Is it hollow, and does it contain anything answering to the seeds found in the bean-pod? Cut it across, and open it up, to see what we may at present call the "young seeds." To which side (upper or lower) of the cavity are they attached?

Make and sketch a longitudinal section of the entire flower corresponding to that shown in Fig. 5.

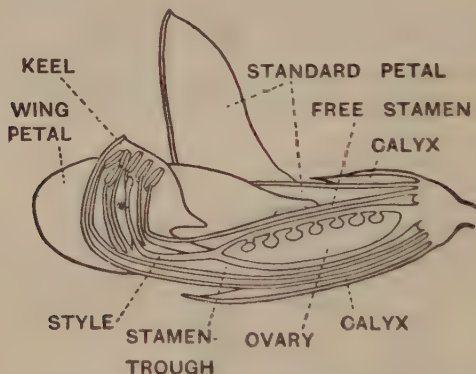


Fig. 5.—Longitudinal Section of Broad Bean Flower.

28. The Fruit.—You should watch some flowers from day to day, or compare different flowers on the same plant, and note any changes that occur as they grow older. What becomes of the calyx, corolla, stamens, style, young pod? What parts of the flower (a) wither, (b) persist, (c) grow larger? Watch the growth of the fruit (pod), opening up pods of different ages, to see what changes have occurred. How does the pod change in texture and in colour as it grows older and larger? How does the ripe pod open to let the ripe seeds out?

Do any changes occur in the rest of the plant (leaves, etc.) while the pods are ripening? What happens if you leave the plant undisturbed in the ground after the pods have ripened? What parts of the fruiting Bean-plant remain alive during the winter? What will next year's plants be produced from?

29. The Seed.—Examine some pods containing seeds, also get a supply of dry seeds (Windsor Broad Bean, about 6d. per quart). Notice the black (or brown) mark on the thicker end of the seed (Figs. 6, 10). How was this mark on the loose seed produced? How does the seed become loose, and what does it break from when the pod opens? This mark may be called the *scar* of the *seed-stalk*. The dry seeds have a shrunken appearance, while fresh seeds are smooth and rounded. In what other respects do dry seeds differ from fresh seeds?

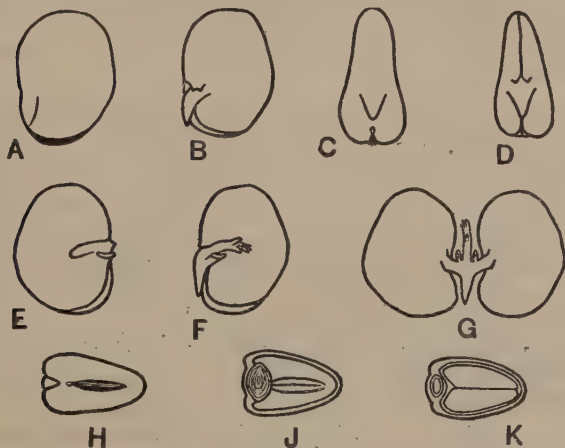


Fig. 6.—Seed of Broad Bean. A, C, and H are views of the entire seed; B, D, E, F, and G are views of the embryo (seed-coat removed); J and K, seed cut across (in J the cotyledons and radicle are removed, to show the radicle-pocket).

Put the dry seeds into water, and notice that in a few days they have swelled and become smooth and rounded, like the fresh seeds. Fill a wooden box, at least a foot deep, with moist sawdust, bog moss, or soil, and plant seeds about half an inch below the surface. See Chapter II. for details of germination. In the young green shoot that comes above the soil notice the forms of the earliest leaves (Art. 33).

30. Seed-coat.—Examine from time to time some dry seeds which have been placed in water, and notice that at first the surface becomes thrown into folds. Cut across the seed, and note that these folds are produced by a *coat* which encloses the contents of the seed. Evidently

the coat at first absorbs water and swells more rapidly than the contents; this loosens the coat and makes it much easier to remove in a seed that has been soaked in water for a day or two.

31. Micropyle.—How does the water enter the seed? Is there any opening in the coat? The folds seen in the soaking seed usually appear first around the *edge* of the seed; this suggests that the water enters somewhere on the edge. Do you recall how we found out that various parts of the bean-plant contained air, which communicates with the atmosphere by openings on the surface of stem and leaves? Perhaps the seed as it lost water took in air, as a piece of wood does in drying. Drop some dry seeds into water that has just been boiled, and notice the stream of bubbles given off. Where do the air-bubbles escape? Wipe this end of the seed dry, in some seeds that have soaked for a few days, and look for the opening; squeeze the seed and see whether water oozes out. This opening is the *micropyle* (Greek, "little gate").

32. Seed-lobes, etc.—Remove the coat from a soaked seed, starting at the end opposite the scar. Note the two large whitish *seed-lobes* or *cotyledons*, whose flat or slightly concave inner sides are pressed against each other. When you have stripped off the upper part of the coat, pull off the rest of it (the part covering the scar end) entire, like a cup. Note the smooth tapering body projecting from between the cotyledons and pointing towards the end of the scar where the micropyle is; also note the little pocket on the inner surface of the seed-coat, into which the projecting body fits. Now pull apart the seed-lobes, and remove one by breaking across the short stalk by which it is joined to the thickest part of the projecting body. This brings to view a curved body lying between the seed-lobes, fitting into a groove on the flat inner surface of each lobe, and forming a continuous line with the projecting body. Has it, like the latter, an even surface, or does it bear any outgrowths? Examine it carefully with the lens, and try to turn back the outgrowths with a pin, without tearing them, so as to make out the positions of the outer ones.

33. The Seedling (Figs. 6, 7, 10).—The first leaf above ground consists of a single piece with its margin cut by shallow notches into three lobes; the second leaf is divided deeply into three lobes, the middle lobe long and narrow, the lateral lobes broad and triangular. Then come several leaves, each consisting of two stipules and a short stalk which bears a pair of oval leaflets (note their folded appearance at first) and is prolonged into a rudimentary tendril. After several leaves like this we get leaves of the mature type, in which the stalk is lengthened below the terminal pair of leaflets, and carries two, three, or four additional leaflets. Have these early leaves,

like the later ones, buds in their axils? In the first two leaves that appear on the young stem the three lobes evidently represent the two stipules and the rudimentary tendril (or the end leaflet which sometimes replaces it).

34. Seedling compared

with Seed.—Carefully pull up a seedling without injuring the root, and compare the latter with the root of the mature plant. Trace the young root upwards and the young shoot downwards, and notice the torn seed-coat and the cotyledons. In the axil of each cotyledon

there is usually a bud. The cotyledons are therefore *leaves*, though differing from ordinary leaves (foliage-leaves) in many respects. They are often called the “seed-leaves.” The young plant, or seedling, has evidently grown from the whole of the seed-contents (*i.e.* everything inside the seed-coat), for we have seen that even the cotyledons are leaves, having buds in their axils. The cotyledons are the first leaves of the young plant, which is called the *embryo* while still inside the seed. The embryo consists of an axis which bears the two cotyledons at about the middle, and which ends in a root* (covered by a root-cap) at one extremity and a bud† (bearing young foliage-leaves) at the other.

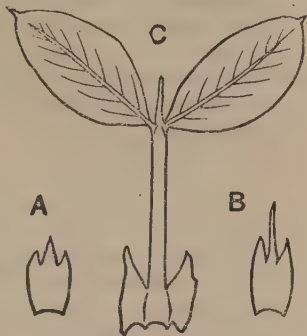


Fig. 7.—Earliest foliage-leaves of Broad Bean seedling.

35. Seedling compared with Mature Plant.

—We have noted the simple form of the earliest leaves as compared with the older ones. The cotyledons are opposite each other and are attached to the same point on the axis, but the early foliage-leaves show the same arrangement (alternate, in two opposite rows) as in the mature plant. The root of the seedling shows the same general appearance and structure as

* The root of the embryo is termed the **radicle**.

† The shoot-bud of the embryo is called the **plumule**.

that of the mature plant, into which it grows, later on forming the characteristic nodules.

If you were unable to get mature Broad Bean plants when you began work, you will find it very easy to raise the plants from seed in pots of soil indoors or in the garden. Some plants should also be raised in "culture solution" (Arts. 131-3).

QUESTIONS ON CHAPTER I.

1. For what purposes is the Broad Bean grown (*a*) by the market-gardener, or in kitchen-gardens, (*b*) by the farmer in his fields?
2. At what times of year is the Broad Bean commonly sown, and during what months may it be seen (*a*) in flower, (*b*) with ripe fruits?
3. How are the lateral roots arranged on the main root in the Broad Bean, and in what directions do they grow?
4. Write down in two parallel columns the contrasted characters of Root and Shoot, as to direction of growth, colour, shape of main axis and branches, appendages carried on axis, etc.
5. Describe the naked-eye features of the main axis (stem), the branches, and the leaves. How are the leaves arranged, and how are they related to the branches?
6. Describe the internal structure of the stem, as seen in sections examined with a lens.
7. Describe the general appearance of a leaf of Broad Bean. Sketch a single leaf, with the part of the stem or branch from which it springs.
8. Describe the arrangement of the hard tissue of root, stem, leaf-stalk, and leaflet. Try to account for the differences you describe.
9. Describe exactly what happens when you pour water on the leaves of a Broad Bean plant.
10. Describe the leaves of any other plants belonging to the Bean family which you have examined, and compare them with those of the Broad Bean, noting the points of resemblance and difference.
11. Describe the naked-eye appearance of the various parts of the Broad Bean flower, with sketches.
12. Describe, from your own observations, what insects may be seen on the Broad Bean plant or visiting its flowers. Which of these insects do you suppose are injurious, and which useful, to the plant?
13. Describe, from your own observations, the changes that occur in the flower from the time it opens until the fruit (pod) is ripe.

14. How does the pod open if allowed to remain on the plant until it is quite ripe, and what do you find inside it?

15. Describe the external features of a Broad Bean seed, with sketches.

16. Describe the parts seen after removing the seed-coat, with sketches.

17. Describe what happens when a dry Bean seed is placed in water, and what you see after planting the soaked seed in soil or sawdust.

18. Describe a young plant (seedling) of Broad Bean, and compare its parts with those seen in the seed.

19. How do the earliest leaves of the seedling differ from those of the mature Broad Bean plant?

CHAPTER II.

SEEDS AND SEEDLINGS.

36. The Germination of the Seed.—We have seen that the Broad Bean seed contains a young plant and is covered by a seed-coat; that the young plant consists of an axis which bears at one end (radicle end) a root-cap, at the other end (plumule end) some young foliage-leaves, and at the middle a pair of large seed-leaves; that when the dry seed is placed in water it swells up; that when the soaked seed is planted in moist sawdust or soil the seed-coat breaks open; that the radicle end of the young plant then grows down into the sawdust or soil and forms the root, and the plumule end grows upwards into the air and forms the shoot, while the seed-leaves remain in their original position; that the young shoot keeps for a time the hooked form which it has while inside the seed-coat, but gradually straightens out as it grows upwards; and that the young plant or seedling which arises in this way gradually grows into a mature plant. The changes that occur, from the time the dry seed is placed in water until the young plant establishes itself, are all included in the term *germination*. The young plant in the dry seed is alive but dormant ("asleep"), and the germination of the seed is simply the awakening of the young plant to active life and growth.

37. Broad Bean seeds (and those of most other plants) germinate best when sown within a year of their ripening; the longer seeds are kept the fewer will germinate and the feebler will be the growth of the resulting plants. Broad Bean seeds will sometimes germinate after being kept for six years. In other plants the seeds may remain alive for a longer time, but the embryo, though dormant, is *living* and therefore gradually losing substance by respiration, besides losing water to the dry air around it.

38. Germination Jars.—Into a large wide-mouthed glass jar put a rolled-up piece of blotting paper, then fill up the jar with sawdust,* keeping the paper pressed against the glass. Place seeds in different positions between paper and glass (Fig. 8), and pour in water enough to moisten sawdust and paper. Fit up a few of these jars, because later on you will have seeds of several kinds to germinate.

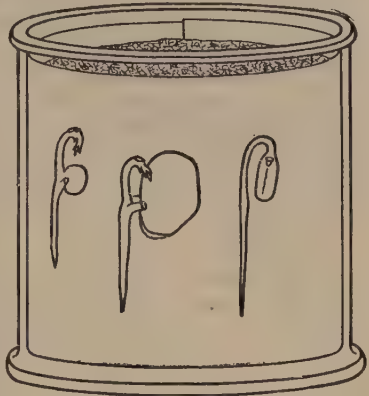


Fig. 8.—Germination Jar.

39. Glass-sided Boxes.
—Get two oblong wooden boxes (depth should be at least a foot for the long roots of Bean seedlings).

(a) Remove one of the longer sides and replace it by a vertical sheet of glass; at each end of the box fasten a strip of wood on each side of the glass, or simply knock tacks in to keep the glass side in position.

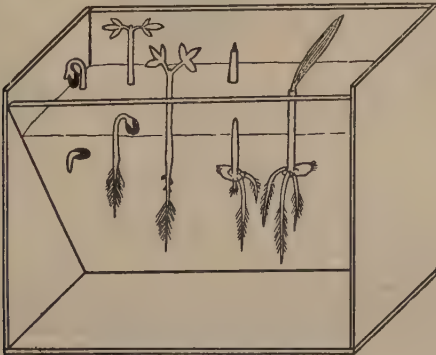


Fig. 9.—Glass-sided Germination Box.

(b) Make a similar box, but fix the glass side so that it slopes downwards and inwards. Fill the boxes with moist sawdust, and place the

* Sphagnum (bog-moss) is better than sawdust; it is easier and cleaner to use, and it retains water better.

seeds close to the glass side, most of them about an inch below the surface of the sawdust, but some lower down (Fig. 9).

40. Early Stages of Germination.—In your germination jars and boxes place (1) dry seeds, (2) seeds that have lain in water for two days. Which of these germinate the more rapidly, other things being equal? How do the young root and the young shoot emerge from the seed-coat? Which is the first to appear on the outside? Notice the V-shaped split in the coat along the edge of the root-pocket, caused by

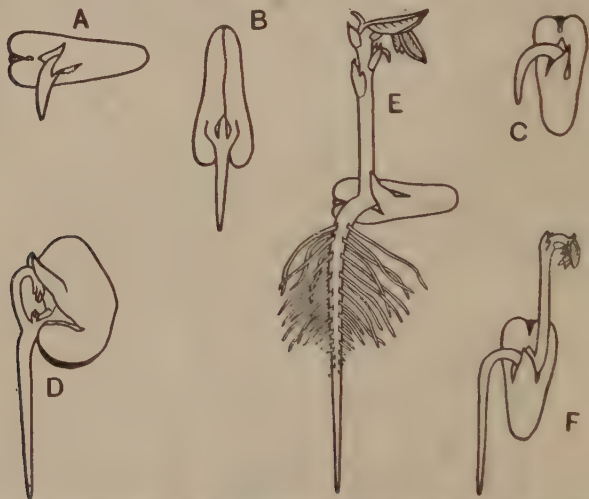


Fig. 10.—Stages in Germination of Broad Bean Seeds, planted in various positions.

the root swelling up and raising the outer wall of the pocket as a triangular flap (does the apex of the triangle reach as far as the opening in the seed-coat or not?). Watch carefully the way in which the stalk of each cotyledon grows in length, pushing the cotyledons apart and allowing the curved shoot to grow out between them. For how long does the young root keep the lead as regards rate of growth in length? What is the advantage to the young plant in the fact that the root emerges before the young shoot? What advantage in the hooked form of the young shoot?

41. Make Sketches (in this case twice the natural size will be large enough, or even natural size if you have acquired a neat style in drawing) of (1) entire seed from the scar end; (2) same from the front, *i.e.* thicker edge, showing the pore and the bulge caused by the root; (3) same in side view; (4) side view showing the triangular flap being pushed off by the growing root; (5) front view showing the same; (6) side and (7) front views of embryo after removing seed-coat; (8) scar-end portion of empty seed-coat, showing the pocket into which the root fits; (9) side and (10) front views of embryo with one seed-leaf broken off; (11) section through whole (soaked) seed, to show pocket with root fitting into it (cut between seed-leaves). Also sketch various stages in germination of seeds planted in different positions and at different depths.

42. What things are needed to make the seed germinate?—What have been the surroundings of the seeds whose germination you have been studying? Write down these things as they occur to you. The seeds were first steeped in **water**, which they absorbed freely, becoming larger and softer; they were then placed in **soil** (or sawdust, used instead of soil for convenience when we want seedlings in different stages for class-work); they have been exposed to **light**, supplied with a certain amount of **warmth**; and lastly (though most obvious of all) they have, of course, grown in the **air**.

43. Is Soil needed for Germination?
—Now, which of these things are absolutely essential for germination? Do you know of any plants which do not grow in the soil, but float on water? Examine the Duckweed plants, so common in ponds; they have roots which hang down in the water.

44. Can you devise a simple experiment to show that a seed can germinate in the air, without any soil or sawdust for the root to grow into? In what condition would the air have to be kept during the experiment? Get a wide-mouthed glass jar and pour into it enough water to cover the bottom to a depth of an inch or so. Then stick a long pin through a soaked Broad Bean seed and fix it into a cork (or a piece of wood to cover the mouth of the jar), inverting the latter so as to bring the seed into the jar (Fig. 11). The seed will germinate in the moist air. Keep this simple piece of apparatus for later experiments.



Fig. 11.

45. Is Water needed for Germination?—Will a seed germinate if kept dry? Place some dry seeds in dry sawdust and others in moist sawdust (an inch below the surface); compare the results after a week or two.

Are seeds able to absorb water from moist air? Can they absorb enough in this way to enable them to germinate? Fold up a piece of zinc gauze to form an open box and suspend it by threads from the lower side of a cork bung (or a wooden cover), so that it can hang down into a wide jar containing some water. Weigh some dry seeds, put them into a gauze box, do not let them come into contact with the water. Weigh the seeds again from day to day, to see whether they have absorbed water from the moist air in the jar. Why do seeds germinate or become mouldy when kept in a damp cupboard?

46. How to dry Seeds, Seedlings, etc.—Are the “dry” seeds sold by the seedsman quite dry, or do they contain any water at all? Into a dry test-tube (warm the tube all over to make sure it is quite dry) put a “dry” seed and heat over a Bunsen or spirit-lamp, applying the flame to the bottom of the test-tube. Notice the drops of water which condense in the colder upper part of the tube. With a dry knife cut a dry seed into pieces and notice that the water is driven off more quickly than when a whole seed is heated; why? Cut 20 dry seeds into pieces; weigh these, and then dry them thoroughly without scorching or charring them at all. This is best done by placing the seeds for a few hours in an oven, or by means of a sand-bath or a water-bath. Then compare the weight of the thoroughly dried pieces and find out the percentage weight of water which the “dry” seeds originally contained (usually about 10 per cent.). This amount of water, though not sufficient to allow of germination taking place, is evidently necessary for the seed to remain alive and capable of germinating.

A simple water-bath consists of two tin cups and an iron tripod to rest them on; half fill one cup with water, and into it put the other cup containing the seeds to be dried. A simple sand-bath consists of a shallow tin or pan filled with sand, supported on a tripod and heated below as usual, the seeds being placed in a smaller tin or a saucer resting on the sand.

47. Properties of Water.—Our experiments have shown that water is necessary for the germination of a seed to begin, that without water the young plant in the seed cannot awake to active life and growth. We shall see later that water is absolutely essential in all the active life-processes of plants. It is obvious, therefore, that we must study the properties of water, so far as they bear upon plant-life.

Study the physical and chemical properties of water, in books on Physics and Chemistry, especially the latent and specific heats of water, solution, evaporation, distillation, filtration, impurities of river or tap water, gases dissolved in rain water, how the composition of water is proved by analysis and by synthesis, etc.

48. How does Water enter the Seed?—If you put some dry Broad Bean seeds into a jar, fill the jar up with water, and let it stand open for a few days you will notice that the seeds swell up but do not germinate (the radicle may burst through the seed-coat), and a scum forms on the surface of the water, which after a time becomes cloudy and ill-smelling. The scum, cloudiness, and bad smell are due to the growth of “germs,” or *bacteria*, which have evidently entered from the air, though some may have been present in the water (unless it was boiled for some time) or on the seeds (unless they were washed with formalin or other substance that kills germs). Bacteria can only grow in the presence of organic matter; hence the seeds have not merely absorbed water, but have also lost some organic matter, which has passed into the water around them. This loss occurs even when the micropyle is sealed up.

In an experiment twenty-five Broad Bean seeds were found to weigh 61·8 grammes; after being kept at 45° C. in a drying oven for two hours they weighed 56·2 grammes, and as this weight was again found on weighing half an hour later it was taken as the actual dry-weight of the seeds. The seeds were placed in water, which was renewed every day, and after five days the soaked seeds were dried at 45° C. till they showed a steady weight of 51·3 grammes. This means that nearly 10 per cent. of the solid matter of the seeds had diffused into the water.

49. Capillarity and Osmosis in Seeds.—Water enters the seed partly by way of the pore (micropyle) and partly through the seed-coat. The radicle, which is just within the micropyle, receives water more quickly than the other parts. The pocket around the radicle doubtless helps to draw water in by *capillarity*, thus making and keeping the radicle moist. Water also enters by *osmosis* through the seed-coat, and at the same time part of the solid matter contained in the young plant passes out, in solution, into the water. This substance which escapes from the seed is largely cane-sugar in the case of the Broad Bean. When the cargo of a wheat-carrying ship becomes damaged by water on a voyage, the weight of the wheat when dried again is found to have suffered considerable loss by sugar passing out into the water. We shall see later how the Bean seed and Wheat grain come to contain sugar after soaking in water and beginning to germinate.

50. Capillarity; Capillary Attraction.—When open glass tubes, having a very small bore, are held vertically in a liquid, there is always a difference between the level of the liquid inside the tube and that of the liquid outside. If a glass tube of this kind be placed in water, the level of the water in the tube will be above that of the water outside, and the surface of the water in the tube will be concave. In the case of mercury, the level inside will be below that outside, and the surface will be convex. The finer the tube, the more marked will the result be. The liquid only ascends when it is capable of wetting the sides of the tube.

51. Osmosis.—When dry raisins are placed in water, they swell up just as dry seeds do. On the other hand, if fresh grapes are placed in a strong solution of sugar, they shrink. The swelling of the dried seeds or raisins and the shrinking of the fresh grapes are due to *osmotic pressure*.

If we place in a vessel of water a bladder filled with a strong solution of a substance having an "attraction" for water, e.g. sugar, a large amount of the water will diffuse (pass by osmosis) into the bladder (*endosmosis*), while a small amount of the solution will diffuse out (*exosmosis*). The weaker solution diffuses faster, and this continues until the same concentration is acquired, when it is equally rapid in both directions, and hence apparently ceases. Meanwhile considerable pressure is set up inside the bladder, owing to rapid endosmosis.

52. Thistle-Tube Experiment.—Get a thistle-tube ("thistle-funnel," with 18-inch tube, 3d. or 4d.), and

prepare a strong (about 10 per cent.) solution of sugar, colouring it by adding red ink if the experiment is to be shown in a class. Get a butcher to clean, inflate, and dry a sheep's bladder for you; cut out a piece large enough to tie over the wide mouth of the tube, and soak it in water. Plug the narrow end with a bit of plasticine, pour into the wide end enough solution to fill the head and an inch or so of the narrow part, tie over the mouth the piece of bladder, invert the funnel, and remove the plug of plasticine. Then fix the "funnel," head downwards, into the cork of a wide-mouthed glass jar containing water, so that the coloured sugar solution in the tube is level with the water (Fig. 12A). Observe the rise of the liquid in the tube of the funnel, also show that a little of the sugar solution diffuses into the water, by evaporating the liquid in the dish to dryness, when a small residue of sugar will remain. If the sugar

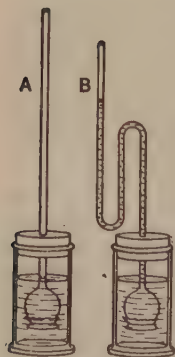


Fig. 12.

solution used is strong enough, the presence of sugar in the water outside of the thistle-funnel may be detected by tasting.

53. Osmotic Pressure.—Careful experiments with suitable membranes have shown that the osmotic pressure set up by a 6 per cent. solution of cane-sugar equals 60 lbs. per square inch, enough to support a column of water about 140 feet high, while a 3 per cent. solution of saltpetre produces a pressure of about 70 lbs. per square inch. Some idea of osmotic pressure may be obtained by using apparatus fitted up like that shown in Fig. 12B (a thistle-tube like this costs about 6d.), the pressure being measured by the rise of the mercury in the bent tube. The pressure set up by endosmosis has an important application in connection with root-absorption (Ch. III.).

54. Is Air required for Germination?—The seeds in your germination jars and boxes are exposed more or less freely to air. It is very easy to find out whether air is essential for germination.

Drop some seeds into a glass jar or wide-necked bottle, fill up with water and cork tightly. As a control, put some soaked seeds into a similar jar, leaving it open and adding a little water each day to prevent the seeds from becoming dry, but not enough to cover them. Ordinary tap-water contains dissolved air, but as a rule seeds immersed in it, in a corked bottle, do not germinate; to make quite sure that no air reaches the seeds, the water should be previously boiled to expel the dissolved air, and the cork sealed air-tight with vaseline or plasticine. To hold the seeds down, fix them into a spiral coil of wire, easily made by winding iron or brass wire round a tube or a stick.

55. The Atmosphere.—As the life-processes of plants (and animals) depend on a supply of air, and are greatly influenced by changes in it, the properties and composition of air must be thoroughly understood by the student of plant-life. Beans get most of their food from the air, directly or indirectly; the water is brought to the roots in the soil as rain; carbon and nitrogen, two essential elements in the Bean plant's food, come from the air, as we shall see later.

Find out all you can (by reading books on Chemistry and Physics and making experiments for yourself) about the composition and properties of air, also about atmospheric phenomena (see works on Physiography and Meteorology).

56. Oxygen.—Air consists chiefly of two gases, oxygen and nitrogen together with other gases in smaller quantities. It contains varying amounts of water-vapour and of carbon dioxide, and traces of ammonia, nitric acid, etc. When metals are heated in the air, they gain in weight; the ash (or *calx*, as it was formerly called) is heavier than the original metal. If a piece of magnesium ribbon is burnt in a closed vessel containing air and standing over water in a dish, the water rises in the vessel, showing that some of the air (about a fifth of the original

volume) has united with the magnesium. Various other experiments prove that air consists of an active gas (oxygen) forming about a fifth of its volume, and of an inactive gas (nitrogen) forming about four-fifths of its volume. All ordinary processes of burning are accompanied by the absorption of oxygen from the air and its union with the burning substance.

57. Nitrogen.—The inactive portion of the air consists chiefly of nitrogen. No direct simple test can be given for the detection of nitrogen in the free condition, because it does not readily react with chemical reagents. It forms about four-fifths of the volume of the air, and is neither inflammable nor a supporter of combustion. It has no action on lime-water nor on litmus paper. By the action of intense heat, or that of an electric current, however, it is caused to combine with oxygen, forming brown fumes of oxides of nitrogen, which dissolve in water to form nitric acid.

Nitrogen is a very important element in the nutrition of plants, since the living substance (protoplasm) of all plants (and animals) contains nitrogen. Most animals obtain nitrogen in the form of complex organic substances (proteids); most plants obtain it in the form of simple inorganic substances (chiefly nitrates). Most green plants are unable to use the nitrogen of the air in making food, but this power is possessed by some Bacteria, and probably the whole of the combined nitrogen found in nature (chiefly as nitrate of soda and potash) has been formed from the air by the action of Bacteria.

58. How to remove Oxygen from Air.—The following experiment gives a useful method for depriving air of its oxygen, or of measuring the volume of oxygen present in air. Into a glass tube of about 100 c.c.s. capacity pour some 20 to 30 c.c.s. of solution of caustic soda, made by diluting that ordinarily used for analysis with twice its volume of water. Next, add as much pyrogallol as can be taken upon a penny piece (photographers will know this light fluffy powder as "pyrogallie acid"). Close the tube at once with a rubber cork, and mark the height of the liquid with a rubber band. Shake up occasionally for at least five minutes, then open the tube below water contained in a tall jar. Water enters; and if you sink the tube till the level of the water inside and outside is the same, marking the position with another band, the remaining air will be found to occupy four-fifths of the original volume. On testing it as before, it will be found to be nitrogen.

59. How much Air is Necessary to enable a Seed to Germinate?—To answer this question, we may confine some seeds in closed vessels containing different quantities of air, and compare the results. Take four glass jars, all of the same size, and provided with well-fitting corks (Fig. 13). Fill these jars to different heights with moist sand, marking each jar into five equal parts, and putting into the first jar enough sand to reach the lowest mark; into the second, sand up to the next mark; and so on. The fourth jar will thus contain four times as much sand, and therefore only a quarter as much air, as the first. Into each jar now place six soaked Beans (or twenty Peas), cork

tightly, and seal with plasticine and vaseline. In which jar do the seeds germinate best? Do the results suggest that germinating seeds cause some change in the air, that they use the air up?

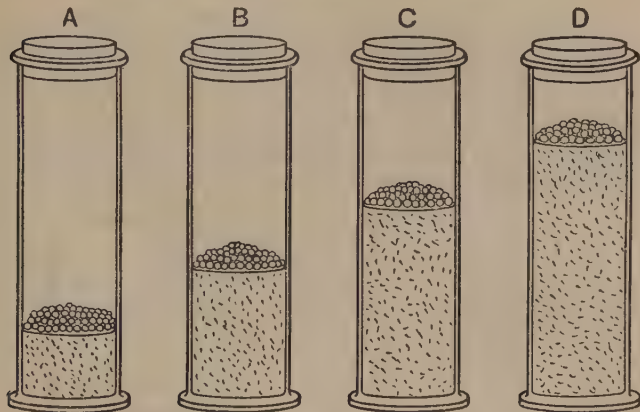


Fig. 13.

After three or four days, carefully remove the cork from one of the jars and lower a lighted taper or match into it: note what happens. Open another of the jars, and dip into it a glass rod which has been dipped into clear lime-water; see Art. 60 (b).

Pour a little clear lime-water into a large glass jar or bottle; cover with a glass plate and shake vigorously: is there any milkiness? Now burn a taper or a splinter of wood in the jar and shake the jar again.

Breathe through a glass tube, several times, into clear lime-water: what happens?

The change in the lime-water is due to the gas carbon dioxide, which combines with the lime-water to form carbonate of lime (chalk), the particles of chalk producing the milky appearance.

60. Respiration of Germinating Seeds.—These experiments show that germinating seeds absorb oxygen and give out carbon dioxide, so that a germinating seed changes the air around it in the same way that an animal does by its breathing. Since the same change is produced by burning in air a candle (which contains carbon) or a piece of charcoal (which is practically pure carbon), we see that the respiration or breathing of a germinating seed, or of an animal, is simply a process of oxidation, a slow burning of carbon. Hence the seed must contain carbon in some form; we shall return to

this point later. Meanwhile, here are some further experiments on the respiration of germinating seeds.

(a) Get a wide-mouthed jar with a tightly fitting cork; bend a glass tube twice at right angles, so that the two parallel legs will be of about equal length, and through a hole in the cork push one of the legs until it nearly reaches the bottom of the jar (when corked). Fill a small muslin bag with soaked Peas, mixed with bits of soaked Sphagnum or clippings of wet sponge, and hang the bag to the lower side of the cork by means of a bent pin. Put a bit of sponge soaked in caustic potash solution * in a small wide-necked bottle or an egg-cup and lower it into the jar (Fig. 14). Smear the top of the cork and the rim of the

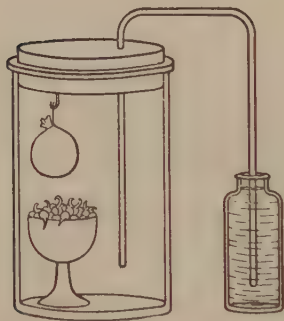


Fig. 14.

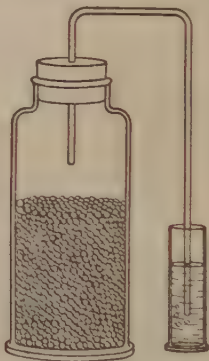


Fig. 15.

jar with plasticine. Put the outside tube in a tumbler or open bottle of water coloured with red ink; keep the apparatus in a fairly warm place, and note any visible result. After a day or two, when you find that no more water seems to be collecting at the bottom of the jar, raise the cork and insert a lighted taper. Now write out an exact account of what has happened during this experiment. What changes in the air have been wrought by the germinating seeds? Why does the water pass over through the bent tube from the vessel outside into the jar?

(b) In the last experiment the carbon dioxide produced by the germinating seeds was absorbed by the caustic potash solution in the sponge. Omit the latter this time; use the same jar (Fig. 15), half fill the jar with soaked Peas or Beans, and fix the bent tube so that the end

* This solution rapidly absorbs any carbon dioxide in its neighbourhood, but the carbonate of potash formed is *soluble*.

of one limb is above the level of the seeds, while the outer limb dips into a bottle containing lime-water or baryta-water.* Set the apparatus in a warm place, and notice the bubbles of carbon dioxide which are given off, and which cause a white precipitate.

(c) Take three U-tubes and three narrow jars (or test-tubes a little wider than the U-tubes). Place in one arm of each U-tube (Fig. 16) six soaked seeds (Peas or Wheat), then invert the U-tube after inserting a cork, with a wad of soaked cotton-wool to keep the seeds moist. Half fill the jars or test-tubes with (1) water, (2) strong caustic potash solution, (3) strong solution of pyrogallol in caustic potash, and place the open ends of the U-tubes in the test-tubes. If you have no suitable narrow jars, support the test-tubes in a stand. Notice that in (3) the solution soon rises in the inverted U-tube (how far does it rise, and why?) and the seeds germinate very little (why?); in (2) the solution rises, more slowly, and to the same extent (why?), and the seeds germinate well; in (1) the water hardly rises at all, though germination occurs as in (2). What has happened in each case? In (2) the seeds absorb oxygen from the air and give out carbon dioxide, which is absorbed by the potash solution, and the latter therefore rises slowly in the U-tube for about a fifth of its length; in (3) the potash and pyrogallol solution absorb the oxygen of the air in the U-tube. Why does the water not rise in (1)?

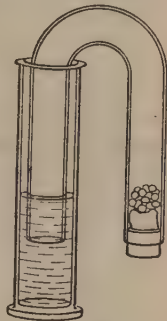


Fig. 16.

61. Heat produced by Respiration.—From the foregoing experiments it is clear that respiration is a process of oxidation, just as burning is, and this suggests that it may be accompanied by the giving out of heat. Do germinating seeds give out heat?

(a) Fit three tumblers or jars with a cork or a cardboard cover, with a hole in the centre through which a thermometer is passed. First compare the readings of the three thermometers by placing them together in water at different temperatures. Half fill one jar with soaked seeds (Peas, Beans, Wheat, or Barley answer well); the second with seeds that have been killed by boiling (add some corrosive sublimate to the water to prevent growth of moulds or Bacteria); the third with moist sawdust (as a control). Place the three jars, with thermometers inserted to equal depth in each, in a box, and put dry sawdust between and around them; cover the whole with a bell-jar or a dry cloth, and compare readings of thermometers at the start of the experiment and then at intervals of a few hours.

* Made by shaking up hydrate of lime (slaked lime) or of barium with water and filtering.

(b) Instead of jars or tumblers use three test-tubes, each with a bored cork for the thermometer; place the tubes horizontally in a cardboard box, with thermometer-stems projecting through holes, and pack round and between the tubes with dry cotton-wool.

62. Warmth required for Germination.—When the temperature of the soil falls to 0° C. nearly all life-processes become dormant, and for most cultivated plants these processes do not begin until a temperature above 5° C. has been reached. There is for all plants a certain range of temperature within which germination is most rapid, and which ensures the highest percentage of plants from the seeds sown. The temperature below which germination does not occur is called the *minimum*, that above which there is no germination is the *maximum*, while the most favourable temperature is the *optimum*; these might be called respectively the *lowest*, *highest*, and *best* temperatures for germination. In general, the temperatures at which the seeds of most cultivated plants grow best in our climate lie between 21° C. and 35° C., with an average about 28° C.

(a) Place some soaked seeds in a glass jar and cover them with moist sawdust; plunge the jar into a box containing pieces of ice, which must be renewed as they melt. The ice will last longer if the box containing it is set into a larger box, and the space between the two boxes is packed with dry sawdust.

(b) Another method is to use two boxes as in the preceding, but to place in the smaller box a single box of ice, with dry sawdust below and around it; place the seeds directly on the ice and cover them with dry sawdust, which will be kept moist by the melting ice.

63. Is Light required for Germination?—This question is very easy to answer by experiment.

(a) Place in a dark cupboard or cellar some jars or boxes containing seeds planted in moist sawdust. Compare with seeds of the same kind, planted and watered in the same way, but set in the light.

(b) A better plan is to keep the two sets of seedlings close together; exclude the light from one lot by covering the jar or small pot in which the seeds are planted by inverting over it a large flower-pot or putting it into a tin or wooden box with a few holes for ventilation. Compare the rate of growth of the two sets of seedlings from day to day, and note any other differences between them.

These experiments will show that **light retards the growth of seedlings**, since they grow faster in the dark.

You will also notice that the darkened seedlings have small pale leaves instead of well-developed green leaves. We shall deal with these differences later.

64. Conditions necessary for Germination.—If you have carefully carried out the simple experiments on germination, for which directions have been given, you will know what conditions are essential for germination of a seed, which contains a live but dormant plantlet. **Water, oxygen,** and sufficient **heat** are the three essentials for the awakening of the young plant from its sleep. We shall see later that for the continued healthy growth of the plant other conditions are necessary, without which the seedling after a time dies.

65. Growth in Light and in Darkness.—If you have carefully performed the simple experiments mentioned in Arts. 59 and 60, you will see on reflection that the germinating seed must lose carbon in its respiration. To measure this loss we must, of course, dry the seeds and seedlings before weighing them. Does this loss occur both in light and in darkness? This is an important point which is fairly easy to investigate by experiment.

(a) Take about forty Beans as nearly alike in size and weight as possible; select four of them as samples, and find their weight after thoroughly drying them on a water- or sand-bath or in a slow oven. Take the dry weight of a seed, found in this way, as the average. Sow half of the seeds in sifted garden soil in a box which is kept in darkness, the other half in a box kept in full light; water both lots about equally. At the end of each week measure and record the average height of the shoot in each lot of seedlings; remove three seedlings from each box,

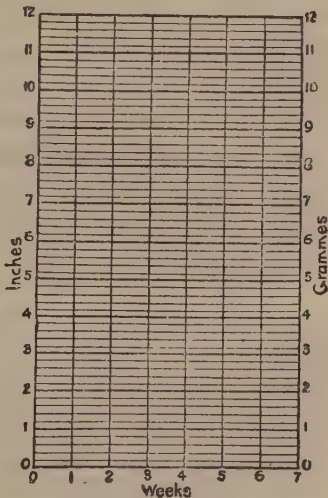


Fig. 17.—Chart on which to plot the Curves of Height and Weight.

wash the roots in running water (do not leave any in the soil or lose them in any way), and dry them thoroughly without charring any part (Art. 46). When quite dry and brittle, weigh each lot and obtain the average weight of the solid matter in each plant. Get a piece of squared paper, as in Fig. 17 (spaces *representing* inches need not, of course, be inches). As the weekly observations proceed, trace two lines across the sheet, one (a continuous line) to show the weight, the other (a dotted line) the height of the seedlings grown in light; draw two other lines in red ink to show the weight, and height, of the seedlings grown in darkness.

(b) Another method is to use Wheat grains, and grow them with the roots in water. From some Wheat count out thirty-six good sound grains, and divide them into batches of a dozen each; see that the weight of each batch is as nearly as possible the same. Dry one batch (A) and record the dry weight. Tie a piece of muslin over a tumbler or bowl filled with water, and put a batch (B) of seeds on the surface of the muslin, which should be kept wet. Another plan is to use a piece of flannel, stab twelve holes in it, and in each hole place a seed. Keep the tumbler in a warm, dark place, and renew the water every second or third day. Plant the third batch (C) as in (B), and keep both at about the same temperature, but when the young shoots appear, expose (C) to the light. When the shoots have grown several inches, carefully remove the seedlings from (B) and (C), noting the difference in colour between the two sets. Dry them thoroughly, without charring even the finest rootlet, and then weigh each lot and compare the weights of (A), (B), and (C).

66. Growth in Soil and in Sawdust.—Have you noticed any difference between Bean seedlings grown in *soil* and those grown in *sawdust*? If you sow the two lots of seeds at the same time, water both lots with equal quantities of tap-water, and keep them exposed to the same conditions as regards light and warmth, which lot will grow best? Try to find out by measuring heights and dry weights, as in the preceding experiments, and plotting the results in curves.

67. The Bean Seed contains Food.—The results of these experiments will show that while a seedling kept in darkness grows more in height, it loses in dry weight, so that, apart from water, it actually weighs less than the seed itself did, and eventually it dies. It is obvious that this loss must be largely due to respiration, and that it is chiefly a loss of carbon in the form of carbon dioxide. The seed must, therefore, contain a store of carbon in some form, and it is at the expense of this stored carbon that the darkened seedling respire and grows. On the other hand, seedlings grown in the light after a time increase in dry weight, and are therefore able not only to repair the loss due to respiration, but are also able to add to their dry weight in some

way. To repair the waste due to respiration and to provide material and energy for growth, the young plant in a seed requires a store of food upon which it can draw during the early stages of germination. Where and in what form is this food stored, how is it made use of, and how does it compare with the store of food placed at the disposal of young animals—*e.g.* in eggs and in milk? From their size and thickness, it is easy to infer that the cotyledons of Beans or Peas form the storehouses of reserve food-stuffs.

(a) Place a piece of Bean-cotyledon on the end of a long needle (a needle mounted in a piece of wood like a penholder is best for purposes like this), and hold it over the flame of a spirit-lamp; notice that it turns black in a few seconds. Rub the charred mass on white paper; it leaves a black mark of charcoal (carbon). Continue to heat the piece for some minutes, and note that it burns to ash.

(b) Heat some dry Beans or Peas in a test-tube fitted with a bent tube passing through a bored cork, and dip the free end of the tube into lime-water or baryta-water. Notice the white precipitate produced by the carbon dioxide set free.

(c) Crush, or cut up into small bits, some Beans or Peas, mix them with three or four times the quantity of soda-lime, and heat the mixture in a test-tube. Fumes of ammonia are given off, proving the presence of *nitrogen*.

68. Food stored in Bean Seed.—From these simple tests it appears that in addition to carbon the Bean seed contains nitrogenous substances and also some mineral matter (ash ingredients). The Bean seed contains all the chief kinds of human food—water, mineral salts, proteids, carbohydrates, and fats.

69. Structure of Bean Cotyledon.—A section through a cotyledon, examined with the microscope, shows an outer layer of small cells containing fine-grained protoplasm (living substance, consisting of proteids) and a darker-staining body (nucleus), while the rest of the cells contain protoplasm and nucleus together with numerous small proteid-grains and larger starch-grains, the latter being white rounded glistening bodies. On adding some iodine solution, the starch-grains are seen to turn blue, while the protoplasm and proteid-grains turn brown. The walls of the cells, or closed chambers of which the cotyledon is formed, consist of *cellulose*, a carbohydrate which is not stained by iodine alone, but turns blue when treated with sulphuric acid and then with iodine. The dry Broad Bean seed contains about 60 per cent. of starch, 25 per cent. proteids, 3 per cent. oil, and 4 per cent. ash ingredients (calcium, magnesium, potassium, sulphur, phosphorus, etc.); the residue consists chiefly of cellulose (in cell-walls) and some silica (in seed-coat).

70. Carbohydrates.—**Starch** and **sugar** both exist abundantly in plants, and are called carbohydrates, because on analysis the proportion by weight of hydrogen to oxygen found united with the carbon is always the same as exists in water—viz. 1 : 8. Starch is insoluble in cold water, but is easily converted into sugar, which is soluble; see Arts. 71 (c), 72 (c), 78, 79. Both resist change when exposed to air, and sugar is even used to preserve various foods from decomposition, as jams, crystallised fruits, etc. A *weak solution* of sugar, however, exposed to the air is soon converted into one of alcohol, by the action of Yeast. Other carbohydrates are the **celluloses, gums, inulin.**

71. Experiments with Starch.—(a) Heat some dry laundry starch in a test-tube. Note the condensation of water in the upper part of the tube. This proves the presence of *hydrogen* and *oxygen* in starch (since water is composed of these elements). Note also that the starch soon begins to *blacken*, proving that it contains *carbon*, and at the same time dirty white fumes are evolved, having a pungent odour somewhat resembling that of burnt sugar. Apply a light to the mouth of the test-tube—the fumes are *inflammable*; introduce a piece of moist blue litmus paper into it—the litmus becomes red, showing that the fumes are *acid*. Introduce a glass rod, on the end of which is a drop of lime-water, into the test-tube. The lime-water becomes milky, showing that *carbon dioxide* is one of the products of decomposition of starch. This confirms the presence of carbon in starch (since carbon dioxide is a compound of carbon and oxygen). When all the volatile matter has been driven off, a black glistening residue of *charcoal* remains.

(b) Shake a very little starch in a test-tube of cold water and boil well; add a few drops of iodine solution: a blue colour is formed. Boil the blue solution, and the blue colour disappears, to return on cooling.

(c) Boil a little starch with dilute sulphuric acid, and test a few drops of the solution from time to time for (1) starch, and (2) sugar. The reactions of starch are gradually lost, and those of sugar appear instead.

72. Experiments with Sugar.—(a) Examine specimens of cane, grape, fruit, and milk sugars. (1) Taste them: they are all sweet. (2) Boil with a solution of caustic potash: cane sugar does not colour the solution, but the others turn it brown. (3) Add a little Rochelle salt (sodium potassium tartrate), then excess of caustic potash, and finally some copper sulphate solution.* [The object of the Rochelle

* This is called **Fehling's test**. Dissolve 35 grammes of copper sulphate in 200 c.cs. of water to make solution A. To make solution B (to be kept in a separate bottle) dissolve 70 grammes of Rochelle salt in 200 c.cs. of 10 per cent. caustic potash solution. Use equal volumes of solution A, solution B, and water.

salt is to prevent the precipitation of cupric hydroxide by the action of potash on copper sulphate.] Boil : cane sugar only precipitates red cuprous oxide on long boiling, but the others give a precipitate at once. (4) Add a solution of silver nitrate to which excess of ammonia has been added, and warm : the cane sugar only reduces the silver after long boiling ; the others do so very soon.

(b) Boil some cane sugar with dilute sulphuric acid for ten minutes, and test with Fehling's solution, etc. : it now gives the same reactions as the other sugars.

These properties of possessing a sweet taste and of turning caustic potash brown and reducing copper sulphate and silver nitrate, either at once or after previous boiling with dilute acids, are characteristic of the sugars.

(c) Moisten a little starch with a few drops of dilute hydrochloric acid and heat gently in a dish. The sticky mass obtained is *dextrin* or "*British gum*." This on boiling for some time becomes malt sugar. Dextrin is also formed by simply heating starch ; it occurs in the crust of bread.

73. Proteids, or nitrogenous food-stuffs, composed of carbon, hydrogen, oxygen, nitrogen, sulphur, and in some cases phosphorus, occur in both vegetable and animal tissue, though only plants can build them up from their elements. They form the living substance (protoplasm) found in cells of plants and animals ; in decaying they give off offensive smells. **Albumin** occurs in white of egg, **myosin** in lean meat, **gluten** in flour, **casein** in milk and cheese, **legumin** in Peas and Beans.

The chief classes of proteids are **albumins** (soluble in distilled water, clotted on heating, *e.g.* white of egg), rare in plants ; **albumoses** (soluble in water, not clotted on heating) ; **globulins** (insoluble in water, but soluble in dilute solutions of salt, *e.g.* yolk of egg, myosin), common in plants ; **albuminates** (insoluble in water or salt solutions, but soluble in dilute acids and alkalies, *e.g.* casein), common in plants (*e.g.* gluten).

74. Wheaten Flour, made from the grains (seeds) of Wheat, makes very convenient material to examine and test for starch and proteids.

(a) Take a tablespoonful of wheaten flour and enclose it in a piece of muslin. Hold it under a tap of gently running water and work the flour about by constant squeezing. Catch the whitened water as it flows away from the flour. In a little time the water passes off clear. Keep working it for a little longer time, then open the muslin and discover a mass of sticky material : this is gluten. Let the muddy water settle, then pour off the liquid and keep the sediment. The sediment is starch ; it forms a large proportion of the flour.

(b) Put a small bit of gluten on the end of a mounted needle, and hold it over the flame of a spirit-lamp; it burns, then turns black. Rub the charred mass on a piece of clean white paper; it leaves a mark of charcoal (carbon).

(c) Mix a little of the gluten with soda-lime, place the mixture in a test-tube, and heat by means of a spirit-lamp. As the gluten decomposes, ammoniacal fumes are given off, thus proving the presence of nitrogen in the gluten.

(d) Put a little of the gluten into a test-tube containing a weak solution of caustic potash. Shake well. Note that the gluten dissolves.

(e) Put another bit of gluten into a small quantity of strong nitric acid in a test-tube or watch-glass. Heat. Note the yellow coloration which deepens to orange if ammonia solution be gradually added. Add the ammonia solution very cautiously with a glass tube, as the action between the acid and the alkali is a violent one.

(f) Place a little of the sticky gluten in a test-tube and warm it. Notice that the heat causes it to solidify. This does not occur with the proteid (legumin) present in Beans and Peas.

(g) Take a little of the milky liquid from the basin. The milkiness is due to starch granules. Boil it; this makes it go clear. Cool the clear liquid, and add a few drops of solution of iodine. A deep blue colour proves the presence of starch. Note that the blue colour disappears on heating.

75. Oils.—Many plants store up food in the form of oil; the corresponding food-store in animals is fat. An oil is a liquid which when dropped on glazed paper makes it translucent, a *fat* as a solid which when melted behaves in a similar manner. Oils and fats are compounds made up of carbon, hydrogen, and oxygen, the oxygen present being insufficient to combine with all the hydrogen and form water. Chemically they are considered to be compounds of “fatty” acids with glycerine. Most vegetable oils are obtained from seeds, *e.g.* *mustard*, *sunflower*, *linseed*, *castor oil*. Others are obtained from the stem, *e.g.* *oil of turpentine*, others from the leaves, *e.g.* *eucalyptus oil*, and others again from the flowers, *e.g.* *lavender oil*, or the fruits, *e.g.* *olive oil*.

76. Oils in Seeds.—Remove the coats from dry seeds of Sunflower, Cress, Mustard, Castor Oil; fold the seeds in blotting-paper and crush between two flat stones (or by any other method), and note the greasy stain produced, which dissolves in ether or alcohol. The young plant in a “Brazil nut” is very rich in oil, as can be seen on cutting the “nut” across, after removing the shell: the oil is made very evident if the knife be heated.

77. Digestion of Reserved Food.—The foods stored up in seeds for the use of the young plants must be insoluble in water, and not able to diffuse through membranes (cell-walls): why? The reserve food in the Bean cotyledons must, however, when the seed germinates, travel from cell to cell through the cell-walls in order to reach the places where it is needed (radicle and plumule), and in order to do this the food must be changed into soluble and diffusible substances. The food stored in a seed must, in fact, be *digested* before it can be used by the young root and shoot, and the process of digestion in a plant is essentially the same as in an animal. Find out all you can, from books on Physiology, about the digestion of starch, proteids, and fats. In the germinating seed, just as in an animal, starch is converted into sugar, proteids into peptones, oils are emulsified and converted into fatty acids and glycerine (which are further changed into sugars, etc.).

78. How is Starch digested?—In the human body the conversion of starch into sugar is partly effected by saliva (formed by glands which open into the mouth) and partly by the pancreatic juice (secreted into the part of the intestine just beyond the stomach). In both cases the change of starch into sugar is due to a substance, called a *ferment*, present in the secreted juice. A similar ferment occurs in plants, called *diastase*; the starch-converting ferments of animals get other names, but might be called *animal diastase*, to emphasise their essential similarity. It is easy to prove that diastase occurs in germinating seeds in which starch is stored. Starch is changed to grape-sugar by being made to unite with the elements of water, the action being called *hydrolysis*. This can be brought about, as we have seen, by boiling starch in water for a long time, or more quickly by adding acid to the water.

79. Experiments on Digestion of Starch :—

(a) Boil a little starch in water and put a little of the cooled paste on the tip of the tongue. After a short time it tastes sweet, showing that some of the starch has been changed to sugar by the diastase (ptyalin) of the saliva.

(b) Mix a little starch paste in a test-tube with saliva, warm it to body-temperature by holding the tube in the hand, or placing it in

warm water, for a few minutes ; then add Fehling's solution, and boil. As a control, test separately for sugar the starch-paste and the saliva before mixing them.

(c) Add to some starch-paste a small quantity of filtered saliva which has been heated to boiling ; after a while apply Fehling's test. No sugar is formed ; the diastase has been destroyed.

(d) Make a thick paste with flour and water, and mix with it some extract of malt. Keep the mixture about the same temperature as the body. The malt quickly liquefies the paste. Test for sugar in the liquid by tasting it, and by Fehling's solution. The first step in the process of brewing is to let Barley germinate until the starch is changed to sugar ; the grain is then killed by heat, and a watery extract (malt) is made ; yeast is then added, by the action of which the sugar is changed largely to alcohol.

(e) Make thin starch-paste by shaking up a little ordinary starch or flour with boiling water and letting it stand to cool. Get some seedlings of Bean or Pea in which the radicle has grown out at least an inch ; remove the seed-coats, grind the cotyledons up with water, and filter through a funnel with filter-paper or thin blotting-paper. Pour the starch-paste into white saucers, putting a label on each. Leave saucer 1 as it is ; into 2 pour a few drops of iodine solution ; into 3 pour some of the watery extract from the cotyledons. Set the three saucers in a fairly warm place, and after a time test 1 and 3 with iodine solution. Notice that the starch-paste with the extract in it soon gives only a reddish colour with iodine, and ultimately remains uncoloured by iodine, showing that the starch has disappeared. Taste the liquid in saucer 3, to which the extract was added : the starch has been converted into sugar by a substance (diastase) which has been extracted from the cotyledons (filter, and to the clear filtrate apply Fehling's test).

(f) Squeeze the milky contents of about half a dozen sprouting Wheat-grains into a test-tube or watch-glass with a little water, and stir. Filter, add a few drops of Fehling's solution to the clear filtrate, and heat. A brick-red precipitate or coloration indicates the presence of sugar.

(g) Try Fehling's test with cotyledons of Bean seedling, also with the young shoot and root ; chop up the parts to be tested.

80. How are Proteids digested ?—Proteids are acted on in the animal body by the gastric juice in the stomach and by the pancreatic juice in the small intestine ; the former contains a ferment, *pepsin*, which acts only in acid solutions, the latter a ferment, *trypsin*, which acts only in neutral or alkaline solutions. Germinating seeds contain a ferment resembling trypsin, which converts the proteids into soluble substances, including peptones. Peptones differ from other proteids in being very soluble in water. Pepsin is only found in a few plants, *e.g.* the pitcher-plant, *Nepenthes*, but vegetable trypsins

are of widespread occurrence, and some of them—*e.g.* papain—are now largely used in medicine. The action of trypsin goes further than that of pepsin, the peptones being converted into simpler substances.

81. Experiments on Digestion of Proteids:—

(a) Get a fresh pig's stomach from the butcher's, cut it open, and wash it out. Next scrape off the inner coat with a blunt knife, and mince it up. Put it into a mortar, and rub it up with some 2 per cent. hydrochloric acid solution. Leave it in a warm place for two hours. Pour off the clear liquid, put it into some very small fragments of hard-boiled white of egg, and keep it at about the temperature of the body. In less than an hour the white of egg (albumin) will probably have disappeared. It has been changed into peptone.

(b) Heat some of the liquid from (a), containing peptone, and notice that no clot is formed; peptone is not coagulated by heat.

(c) Get a fresh pig's sweetbread, chop it up finely, and put it to soak in a 1 per cent. solution of sodium carbonate. Pour off the clear liquid, and use part of it to show that it turns the starch into sugar. Use the other part to show that it digests coagulated albumin.

82. How are Oils digested?—In the human body the bile and the pancreatic juice act upon fats. They produce what is called "emulsification." This simply consists in breaking up the fat into very tiny globules, which remain suspended in the liquid and do not run together again. If oil is shaken up briskly with water it is broken up into small globules, but these run together again on standing. By first adding a little carbonate of soda to the water, and then shaking up with oil, a much more permanent effect is produced, and this milky fluid may be allowed to stand for some time without any of the oil running together again. The emulsification of fats by the bile and the pancreatic juice is greatly aided by the *chemical change* that the pancreatic juice causes fats to undergo. It splits the oil into glycerine and a fatty acid (see Art. 77). The fatty acid unites with the alkaline salts of sodium that are present and forms a soap. This power of changing fats into glycerine and soap (both of which are soluble in water, and can readily pass by diffusion through cell-walls) is due to the presence of a ferment called *lipase* (steapsin) in the pancreatic juice. Lipase also occurs in seeds in which oil is stored.

83. Experiments on Digestion of Oils :—

(a) Pour a few drops of linseed oil into a test-tube, and add a little water (about 1 in. deep). Place your thumb over the end of the test-tube, and shake the contents vigorously. Note the appearance of the mixture, and put the test-tube in the stand for a quarter of an hour. It will then be noticed that the milky appearance has disappeared, and that the oil and the water have separated again into two distinct layers. This is only temporary emulsification.

(b) Repeat (a), but this time add a pinch of carbonate of soda to the water before shaking up. The emulsification produced this time is of a much more permanent character.

(c) Shake up some linseed oil with its own volume of 50 per cent. alcohol (diluted methylated spirit) and test it with litmus papers: it is neutral. Add to the mixture some castor-oil seeds which have just begun to germinate (crush or chop them up), and test again with litmus after a few hours: notice the acid reaction due to fatty acids.

(d) Heat a little glycerine with small pieces of acid potassium sulphate for a few minutes: note the sharp, pungent smell produced. Test some of the liquid from (c) in the same way: the characteristic smell (of acrolein) shows that glycerine is present. Another test for glycerine is to add a few drops of copper sulphate solution and then potash solution; a deep blue colour is produced, but no precipitate.

84. How long does the Seed's Food last?—We shall see later that green plants get their food from two main sources, air and soil. The young plant in a seed has a store of food for its early growth, a store which is sometimes very scanty and sometimes (as in Bean and Pea) very abundant. We know that tap-water and even rain-water are not pure, but contain dissolved substances, while soil-water or river-water will be much richer in dissolved matter. In order to find out how long the stored food lasts, we should therefore use *distilled* water, so that we know exactly what the roots have had at their disposal; we may use well-washed sand and water it with distilled water. Seedlings whose roots grow in pure water do not live very long, as a rule, especially if they are kept in darkness, when their dry weight diminishes, and they die after using up the stored food. In the light, however, the seedlings live longer, and for a time increase in dry weight. Bean and Pea seedlings exposed to light, with their roots in distilled water, grow for several months and may even produce flowers, though they are small and weakly as compared with seedlings grown in soil. Small seedlings, with scanty food-stores—e.g. Mustard—live only a few weeks when

exposed to light and supplied with distilled water, and only for a few days when kept in darkness.

(a) Deprive Beans and Peas of one or both cotyledons, and observe the result. Remove the cotyledons, in different cases, just after the seed has soaked, after the root has grown 2 ins. long, after the plumule has grown 2 ins. long.

(b) Grow various seeds in jars containing distilled water, fixing them either into holes in muslin or flannel, or into split or bored corks; fill up the water as required, but always use *distilled* water. Keep some of them in darkness, expose others to the light, and compare their growth and their increase or decrease in dry weight. Another method is to let the roots grow into sand that has been washed thoroughly with tap-water and then with distilled water, using the latter for watering afterwards.

85. How is Food transported?—The foods produced by the action of ferments are soluble, and therefore able to travel to the places where they are needed, to supply material and energy for the growth of the young root and shoot. It is easy to trace the passage of the digested foods, especially in the case of sugar, because whenever the sugar accumulates some of it is changed back to starch, for a time at least.

In seedlings of Bean, Pea, and other plants you are growing, note that the root and shoot of the ungerminated seed as a rule contain no starch, but that after germination has begun, starch appears in the young root and shoot; cut these parts longitudinally, and apply iodine solution to the cut surfaces.

86. Energy furnished by Foods.—The amount of energy supplied by a food may be found by measuring the heat produced by burning it, and it is therefore called the *fuel value*. The fuel value of carbohydrates and proteids is about the same, that of fats is more than twice as great. In plants, as in animals, the energy is obtained from the food by oxidation (= burning), and carbon is the principal substance burned, setting free carbon dioxide. Burning 1 gramme of carbon sets free enough energy to raise 8 kilograms (= about 2 gallons) of water from 0° to 1° C., and about 2 litres (about 2 quarts) of carbon dioxide are given off. If all this energy were used in mechanical work, it would suffice to raise 3,400 kilograms through 1 metre (*i.e.* to raise more than 3 tons a yard high). The energy is used up by the plant in the form of heat and of chemical work, in addition to mechanical work.

87. Emergence of Seedlings from the Soil.—You will have noticed the way in which the plumule of the Bean protects the young leaves from injury by bending backwards at the tip as it pushes its way upwards. Seedlings can grow through hard and stiff soil, and in doing this the plumule must exert considerable force. The shoot of a Broad Bean seedling can push upwards with a force of over a pound, and since its diameter behind the hooked part is about one-eighth of an inch, the force exerted = 80 lbs. per square inch. From the fact that the cotyledons of a Broad Bean of average size contain altogether over a gramme of carbon, it is easy to see that the seedling can get a large amount of energy by using the stored food.

(a) Plant some Beans about 3 ins. deep, and pack stiff clayey soil (or plasticine) firmly above them. Watch them to see whether they emerge at the sides or whether they push the whole mass of clay upwards.

(b) Invert a short test-tube over a Bean seedling with a plumule about 3 ins. long, then place over this a vertical glass tube open at both ends, inside which the test-tube can slide freely, and clamp this tube to a support. Into the upper end of the open tube place a second test-tube containing mercury or shot. Mark with a paper strip the level of the top of the shoot, and see what weight of mercury or shot is required to prevent the shoot from continuing to grow upwards. Another method is to use a spring inside a closed tube in place of the mercury or shot; measure how much the force of the shoot, pushing up its tube, compresses the spring, then find what weight is needed to compress it to the same extent.

88. Other Seeds and Seedlings.—We still have several experiments to make with Broad Bean seedlings. Therefore you should have seedlings ready in different stages of growth, besides making observations on those which you sowed in soil in pots or boxes, indoors as well as in the garden; the latter should by this time be in flower, or even in fruit.

Now examine the seeds of a few other plants for comparison with those of the Broad Bean. If you are really interested in Plant-life and have sufficient time, you should examine and germinate the seeds of all kinds of plants, both wild and cultivated. This easy and interesting line of work is perhaps unrivalled as a means of gaining an insight into the physiology of plants, their adaptations, and their evolution.

89. French Bean and Scarlet Runner.—First get some seeds of Dwarf French Bean (*Phaseolus vulgaris*) and of Scarlet Runner (*P. multiflorus*). In both notice the position of the scar; the micropyle, made conspicuous by its raised margin; the wrinkling of the coat while the seed is soaking; the two very distinct foliage leaves of the young shoot, with the veins plainly visible; the small root-pocket inside the seed-coat. Make sketches of these seeds and compare with those of Broad Bean (Fig. 18).

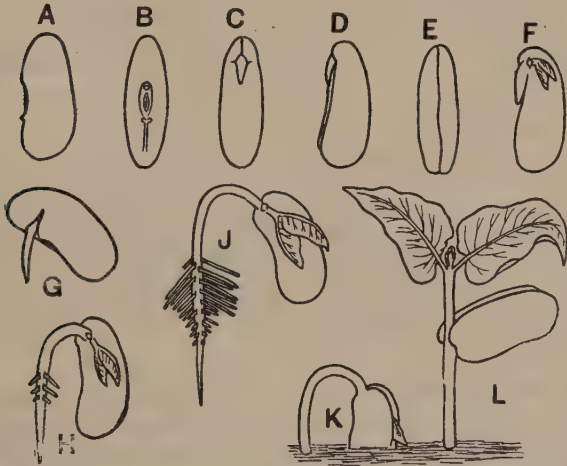


Fig. 18.—French Bean. A and B are views of the entire seed; C to F are views of the embryo (seed-coat removed); G to L are stages in germination.

Sow the seeds of these two plants and observe carefully what happens in germination. In the Runner, the cotyledons remain below the soil as they do in Broad Bean; the cotyledons are in this case termed *hypogeal*. In the French bean, however, the cotyledons are pushed upwards into the air, along with the young shoot, and are therefore termed *epigeal*. How does this come about? Place seeds of the two kinds in your germination-jars or glass-sided boxes (Arts. 37, 38) and watch their germination. The best plan is to remove the seed-coat from the soaked seed, break off one cotyledon (as in Fig. 18f), and place within the glass the rest of the plantlet. You should be able to find out for yourself that the carrying-up of the cotyledons in the French Bean is due to the growth of that portion of the young plant's axis

which lies between the cotyledons and the root. From its position, this region is termed the *hypocotyl* (Greek *hypo* = below). The same thing occurs in many other plants—in the vast majority of plants, in fact, the cotyledons are epigeal. In most cases, carried-up (epigeal) cotyledons are, or become, thin and expanded like typical foliage-leaves, but this is not the case in species of *Phaseolus* whose cotyledons come up into the air. Note the shrivelled appearance of the cotyledons in the Scarlet Runner seedling.

You will notice that while the first two foliage-leaves are simple and heart-shaped and stand opposite each other, the later ones are compound, having three leaflets, and arise singly from the stem; what other differences can be observed? Notice the very regular arrangement of the side-roots in four rows on the main-root.

Sow Scarlet Runner seeds in soil in pots and in garden border, so as to get flowering and fruiting plants for study later on. Why is it necessary to sow the seeds of this plant near sticks or other supporting objects?

90. Garden Pea.—In the Garden or Eating Pea (*Pisum sativum*) notice that the transparent coat enables one to see clearly in the soaked seed the scar, the micropyle, and the root, all lying in the same line with the root-tip pointing to the micropyle. The cotyledons remain below ground, and the earlier foliage-leaves resemble those of the Broad Bean seedling. The later leaves are rather like those of Broad Bean (in what respects?), but the uppermost leaflets are developed as tendrils.

91. Sweet Pea.—Get seeds of Sweet Pea (*Lathyrus odoratus*) and sow them in pots and in the garden. In what respects do the seeds and the seedlings (*a*) resemble, (*b*) differ from, those of the Garden Pea? Why do Peas, like Runner Beans, need to have sticks or other supports placed near the young plants? For how long can they grow without supports? What happens if no sticks are placed near them?

92. Oak (Fig. 19).—In autumn get some ripe acorns, also unripe ones still attached to the “cup.” Notice the circular patch at the broad end; how is this patch caused? Pull an acorn out of its cup; the patch is a *scar*. What do you see at the narrow end? If you had examined very young acorns, you could tell at once that this end bore a tuft of three projections, which served to catch pollen and were the *stigmas* of the “female” flower. Sometimes only the *style* which carried

these stigmas remains on the ripe acorn as a short stiff outgrowth. These facts show that the acorn is not a seed, but a *fruit*. The hard coat is not the seed-coat; it corresponds to the shell of the Bean-pod.

Peel off the coat and notice the thin skin inside it; cut across the white contents of the acorn near the broad end and notice the line running across. Does the white mass split readily into two lobes, as do the seeds of Beans and Peas? What does this splitting indicate? Pull the lobes apart and notice that one bears at its pointed end a conical pointed body, while the other shows in the corresponding place a groove; sometimes half of the pointed body remains on one lobe and half on the other. The appearance of this body suggests that it is the young root, while the two lobes are evidently cotyledons. The young shoot is small, but quite visible. The acorn, therefore, contains a seed, consisting of a plantlet covered by a thin seed-coat. It answers to a Bean-pod in which only one seed has ripened; one-seeded pods occur in Clovers, etc. The acorn is an example of a one-seeded fruit;* such fruits are called *akenes* (or *achenes*) when they do not open to let the seed out.

Soak ripe acorns and sow them. Look for Oak-seedlings near the trees. Notice the splitting of the hard shell into several teeth at the narrow end, the emergence of the root, and the curious pushing-out of the young root and shoot by the elongation of the cotyledon-stalks, between which the shoot grows up. The earliest foliage-leaves have their edges even, or only slightly lobed, but otherwise resemble the later leaves. The cotyledons gradually shrivel inside the split shell; do they contain food at first (test with iodine)?

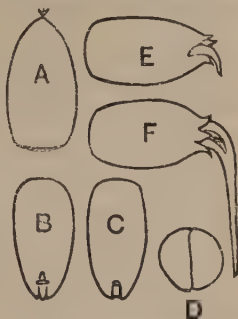


Fig. 19.—Germination of Oak.

* Sometimes acorns have two or three seeds instead of one; this is easily seen when germination takes place and the roots of the young plants have grown out. There may be as many as six seeds.

93. Sycamore (Fig. 20).—In autumn get some “keys” of the Sycamore Maple. The keys are at first joined in pairs (sometimes threes) and each has a “wing.” Watch the keys being blown from a Sycamore-tree on a windy day, noting their spinning or whirling movement through the air.

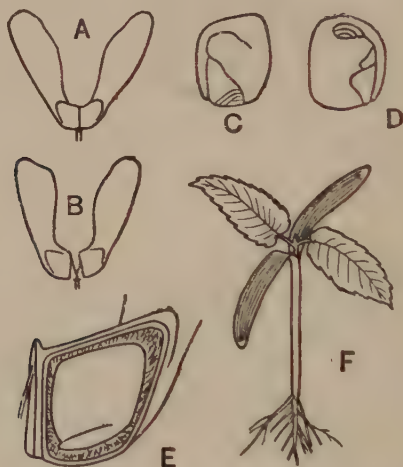


Fig. 20.—Fruit, Seed, and Seedling of Sycamore.

Does this movement carry them a long way from the tree? What causes the keys to whirl? Can you see how the whirling movement causes the “seed” to bore its way into soft moist soil? Throw keys into the air or drop them from a height, noticing how they fall (if calm) or are carried away (if windy). Repeat the experiments with keys from which the wing has been removed; compare the times taken for winged and wingless “seeds” to fall through the same distance.

If you have examined the green flowers of this tree, you will know that the keys are formed from the chambers of the ovary, each of which is produced into a flat outgrowth at the upper and outer edge; this outgrowth becomes the wing. The two keys split apart when ripe, but for a time they

dangle at the ends of a Y-shaped thread whose lower end is attached to the flower-stalk.

Open up the chamber of a ripe key and notice the brown-coated seed. Where is the seed-stalk attached, and what do you notice about the inside of the chamber? Carefully peel off the thin brown seed-coat and note the long curved root. Evidently the young plant fills the whole seed, as in the Bean, while the key itself is, like the Acorn, an akene. Sketch the young plant, then try to straighten out the long strap-like cotyledons (they will be less brittle if the seed is soaked in water), noting the peculiar and neat way in which they are folded and wrapped up. Try to find the small shoot-bud between the bases of the cotyledons. Sow some keys and sketch stages in their germination. The root emerges from the side of the key where it split from the companion key; the cotyledons are carried up into the air and become straightened out. The young shoot does not grow out so quickly as in the case of a Broad Bean or an Oak-seedling; the cotyledons of the Sycamore do the work of foliage-leaves (to be studied later), whereas in Broad Bean and Oak the cotyledons serve as storehouses of food. Carefully compare the Oak and the Sycamore with reference to the structure of the seed and its mode of germination, and think out the advantages and disadvantages of these two types of seedling.

As in the case of the Oak, you can at the right time of year (during which months?) get seedlings of the Sycamore, both near the trees and at considerable distances from them. Notice that the earliest foliage-leaves are simpler in outline than the later ones (Fig. 20 F).

94. Sunflower (Fig. 21).—Get “seeds” of this plant, and if possible Sunflower heads of different ages showing flowers and fruits. In this case, as in Oak and Sycamore, the “seeds” are really dry one-seeded fruits (akenes). The Sunflower akene is attached to the plant by its narrow end (compare with Oak), and the hard shell is the fruit-coat; the upper parts of the flower fall off and leave only the fertilised ovary, *i.e.* the akene.

Soak some akenes in water for a day or two and note that the shell splits along the edge into two pieces to let the root emerge from the pointed end. The seed is attached by a

short stalk to the pointed part of the akene; it has a thin coat and contains an embryo (note the two flat cotyledons, root, shoot). The cotyledons come above ground and turn green. The stalk (hypocotyl) which carries them up is at

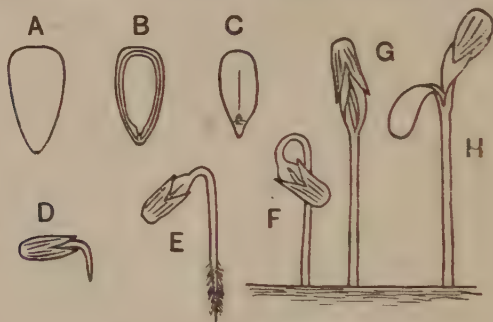


Fig. 21.—Germination of Sunflower.

first bent downwards at the top. This hook or loop is seen in very many seedlings, whether the cotyledons stay below or come up; in the former case it is the part above the cotyledons that is hooked, in the latter case it is the part below them (hypocotyl). Test the cut surface of a Sunflower cotyledon with iodine solution: it gives a brown stain. No starch is present, the reserve-food consisting of oil and proteids; Sunflowers are grown in Russia, etc., for the oil in the seeds, used in making oilcake.

95. Maize (Fig. 22).—Get some Maize “seeds,” also a Maize “cob,” from a corn-merchant. The seeds of the “White Horsetooth” variety are much better for our purpose (because larger and more regular in shape) than the ordinary “Indian Corn” sold for poultry-food. A glance at the cob, on whose axis the grains are crowded, shows that the narrow end of the grain is the fixed end, while the examination of a young cob shows that the thick end at first bears a long feathery outgrowth—the *stigma*. The ripe grain of Maize is therefore a *fruit*; the stigma has fallen off and left no trace.

On the outside of the grain, notice (1) the withered remains of the stalk at the narrow end, and (2) the oval patch on one side. Examine the patch carefully, using

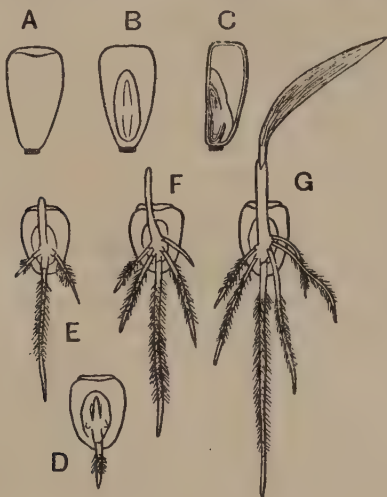


Fig. 22.—Germination of Maize.

several grains, and see if you can make out two ridges on it; one occupies the upper part of the patch (*i.e.* towards broad end of grain), the other the lower end, and both are in the same straight line drawn longitudinally through the middle of the patch. With a knife catch at the pointed end of the grain and tear off the thin transparent tough skin. Then try to learn something of the structure of this patch. Are the two ridges caused by outgrowths from the patch? Try to raise them from the patch by putting the point of the knife-blade below each ridge. If you do this carefully you will see that these are two appendages which are fixed to the middle of the patch; the free end of one points upwards (*i.e.* to broad end of grain), that of the other downwards. Perhaps this is all you can make out of the structure of these appendages at present. Does the oval patch itself lie

on the surface of the grain, or does it project some distance into the inside of the grain? How can we determine its shape and position? Lay a grain on the table with the patch-bearing side uppermost (choose a grain of regular shape) and make a clean slice down the middle of the patch. If you have cut in the right way, you should see the two appendages plainly, attached to a fairly thick structure which projects deeply into the grain and runs obliquely across its interior. With the knife-point, or a pin or needle, gently poke the two appendages about; you will find that the lower one is a solid peg, while the upper one separates into layers. The upper appendage is the young *shoot*, bearing leaves, the lower one is the young *root*; this will be more apparent when you compare the seedling with the seed. What is the shield-like oval body to which these appendages are attached? If you recall the appearance of a Bean embryo from which one of the cotyledons has been removed, you will probably conclude that this oval body is the cotyledon of the Maize embryo. To see the shape of this "cotyledon" more clearly, try to remove the embryo from a well-soaked grain; by carefully scraping the convex surface and freeing this body from the rest of the grain, you will see its shield-like form more clearly. Some botanists prefer not to call this body (found in the grains of Grasses and Cereals) the cotyledon; it might be simply called the *shield*. What does the white inside of the grain suggest as to the probable nature of the stored food? If the shield, the root, and the shoot together make up the young plant, what is the *rest* of the seed? Smear the cut surface (longitudinal section) with iodine solution. This produces a vivid contrast between the young plant and the rest of the seed; the former is stained brown (proteid), the latter blue-black (starch), the two parts being separated by a sharp line. If the grain has been in water for some time, some starch will be present in the young plant. The starch-containing part of the Maize grain is something which is not represented in any of the seeds we have so far examined. It therefore deserves a special name, and it is called the **endosperm**. The Maize seed is said to be an *endospermic seed*, because in addition to the young plant present in all seeds it contains a tissue or region in which food is stored. Seeds which contain no endosperm,

that is, nothing except a young plant, are called *non-endospermic seeds*, e.g. Beans, Peas, Oak. In non-endospermic seeds the stored food is contained in the young plant itself, usually in the cotyledons.

When Maize germinates,* the young root appears first and grows vertically downwards. It bears rootlets, but it does not (as in Bean, Pea, etc.) give rise to the whole root-system of the plant. Examine seedlings of different ages; in one showing the first green leaf, study (1) *the root system*, (2) *the shoot system*.

(1) Note that two, three, or more roots have grown out from the base of the young shoot. Examine the bases of the roots by means of a lens, and observe in each case the minute sheath out of which the root appears to grow; this sheath is produced by the newly formed root bursting through the tissue of the parent axis.

(2) Observe the tubular sheath through the burst apex of which the first foliage-leaf has made its appearance. Compare this with earlier stages of germination, especially noting that at first the sheath is closed at the tip; that for some time—certainly for so long as it remains under the soil—it grows at the same rate as the oldest leaf of the enclosed bud, but that sooner or later it gets burst by the rapidly elongating foliage leaf after the tip of the cone is carried well out into the air.

Make a longitudinal section of the grain and the young shoot, taking care as nearly as possible to bisect the central axis of the embryo. Observe that the “flour” or endosperm of the grain, especially in the neighbourhood of the developing plantlet, is reduced to a pulp. The shield-like cotyledon remains in its original position and acts as a digesting and absorbing organ; it produces the ferment (diastase) that changes the starch stored in the endosperm-cells into sugar, which then must pass in solution through the cotyledon to reach the young root and young shoot. This is easily observed, for whenever sugar accumulates in any part of a plant it is partly re-converted into starch. The action begins

* You will find that Maize germinates very slowly unless supplied with more warmth than most of the other seeds so far mentioned. Wheat germinates quickly, and might be used first.

as soon as the grain has absorbed water, and the iodine test shows that starch appears in the young plant. In the "Sugar Maize" the conversion of starch into sugar begins before germination, so that the grain contains a good deal of sugar.

96. Wheat resembles Maize in the general structure of the grain and the mode of germination, but there are several differences in details, which should be carefully noted.

In a soaked Wheat grain, note the deep furrow running along one side, the small projecting body (embryo) at one end of the opposite side, and the tuft of hairs at the other end. Sketch each side of the grain. With a needle remove the coat of the grain over the embryo, so as to see the radicle and plumule, behind which lies the shield-like cotyledon. Slice the grain longitudinally, cutting down the groove, and sketch what you see (use a lens). Touch the cut surface with iodine solution: the endosperm turns nearly black, the embryo brown. With a needle raise the radicle and plumule from the cotyledon; in the plumule note the young leaves, which can be separated by using the needle.

Sketch stages in germination, noting the arrangement of the foliage-leaves in two rows, their grass-like form, the parallel veins joined by delicate transverse veins. In a seedling showing the second green leaf, examine the root system and shoot system, as described for Maize (Art. 95). Notice the shrunken appearance of the grain, which is now soft and pulpy. Squeeze the grain and notice the milky or watery fluid which escapes; the milkiness is due to the presence of the minute starch grains. Taste the fluid: it contains sugar. Examine some of it with the microscope, and notice that the grains are corroded and broken up while the starch is being converted into sugar. Tear open the grain, wipe away the pulpy contents, and notice the white "shield" (cotyledon), which secretes the diastase required for the conversion of the starch into sugar and through which the sugar passes to the growing parts of the root and shoot systems. See Fig. 9 (Wheat seedlings at right).

97. Further Work with Seeds and Seedlings should be carried out as time permits. Soak, dissect (remove coat, cut sections), and examine with lens as many different seeds as possible. Test out sur-

faces with (1) iodine solution for starch (blue) and proteids (brown); (2) a drop of strong sugar solution, followed by a drop of strong sulphuric acid (bright red colour = proteids); (3) nitric acid and ammonia (yellow colour = proteids). Practically all seeds contain proteids, together with starch or oils. If the seed gives only a brown colour with iodine, showing the absence of starch, try the tests for oil (Art. 76), and for cellulose (Art. 69). Cut thin sections and examine them with the microscope. In Maize and Wheat note the outermost layer of cubical cells in the endosperm, packed with proteid grains ("aleurone-grains"), also the layer of columnar cells (epithelium-layer) on the surface of the cotyledon, which secretes ferments.

Sow the seeds in moist sawdust or soil, note the temperature required (or most favourable) for germination in each case; examine and sketch the seedlings from time to time. In moistened seeds of Linseed, Cress, Turnip, Mustard, notice the jelly formed by the swelling of the gummy seed-coat when it absorbs water. Small seeds—e.g. Cress, Mustard, Wheat—are most conveniently grown on muslin or flannel stretched over a tumbler filled with water; examine the roots for root-hairs and rootlets.

98. Seeds with Food stored in Young Plant.—Examine the seeds and seedlings of Linseed, Cress, Mustard, Turnip, Radish, "Garden Nasturtium" (*Tropaeolum*), Horse-Chestnut, Vegetable Marrow, Melon. In nearly all cases the cotyledons are carried up into the air by the lengthening of the hypocotyl. In Horse-Chestnut the large cotyledons are partly fused together; notice that on germination the young stem and root are pushed out of the seed by the lengthening of the cotyledon stalks. In Vegetable Marrow and Melon notice the method by which the seedling gets its cotyledons out of the cavity enclosed by the rigid walls of the flat seed; an outgrowth ("peg") is formed to hold down the lower half of the seed-coat against the soil, while the growing shoot raises the upper half of the seed-coat and thus gets free. In Mustard the cotyledons are two-lobed, while in Cress (Fig. 9), they are three-lobed. In the "Nasturtium" (*Tropaeolum majus*) the later leaves have a nearly circular blade with even margin, and the stalk is inserted at the centre of the lower side of the blade, but in the earliest leaves of the seedling the leaf-blade is lobed and the stalk inserted at the lower margin, as in the adult leaves of the closely-allied leaves of the Canary Creeper (*T. canariense*).

99. Brazil-Nut.—In this seed the hard shell is the seed-coat; the cotyledons and shoot, which are very minute, occupy the broader end of the embryo, the root being at the narrow end. The greater part of the embryo consists of the swollen axis (hypocotyl), whose cells contain proteid grains and oil-drops (Art. 76).

100. Endospermic Seeds.—In many seeds the stored food is not contained in any part of the young plant itself, but in a special part of the seed called the **endosperm**, which lies within the seed-coat but outside of the young

plant (embryo). In some cases the endosperm surrounds the embryo (*e.g.* Castor Oil, Ash). In others the embryo is coiled around the endosperm, *e.g.* Buckwheat. In all cases, however, the radicle of the embryo is close to the surface of the seed, just within the micropyle. In Maize, Wheat, and other Cereals and Grasses, the embryo and endosperm are sharply separated by a plane drawn across the seed. Unfortunately the old term "albumen" is often used instead of endosperm, and this sometimes leads to confusion. Endospermic or "albuminous" seeds are seeds whose food is stored in a part *outside of the embryo*, and this food may be chiefly starch (*e.g.* Maize) or largely oil (*e.g.* Castor oil), or cellulose in the form of much-thickened cell-walls (*e.g.* Date). The term "albuminous" does not, therefore, imply the presence of proteids similar to egg-albumin, though seeds *do* contain proteids.

101. Castor Oil.—Notice the spongy mass covering one end of the seed; the hard seed-coat, the oily endosperm, the embryo in the middle of the endosperm, with thin cotyledons pressed together (try to find root and shoot); cut longitudinal and transverse sections. The spongy mass (aril) soaks up water; prove by placing seeds in hot water that this mass lies close to the micropyle.

102. Ash.—Steep the fruits ("keys") of Ash-tree in water, then cut open the fruit-cavity and notice the flat seed suspended at the end of a long stalk which runs along one edge of the seed. Slice away one of the flat sides of the seed and expose the straight embryo, lying in the midst of the horny tissue (endosperm) filled with reserve food.

103. Date.—Examine a Date seed (*i.e.* the "stone"). Notice the deep groove along one side. Scrape the surface on the other side, to see the small embryo embedded in the stone (endosperm). Cut the stone across at this point; then dip the stone in dilute sulphuric acid and apply iodine (test for cellulose). Plant some Date stones in damp sawdust or soil, set in a warm place (a heated greenhouse, if possible), and sketch stages in their germination. Open the stone in some of the seedlings, and then notice the softening of the stone and the extent to which the cotyledon has grown inside it. Notice in sections of the stone that the cell-walls become thinner, and that starch grains are formed in the young root and shoot, in darkness as well as in light. The digestion (conversion into sugar) of the reserve food (cellulose) is due to the secretion of a ferment (cytase) by the cotyledon.

104. Onion.—Examine a seedling of Onion before the embryo has finally withdrawn its cotyledon from the seed. Observe (a) the long slender *root*, (b) the slight swelling at the base of the root marking the position of the relatively short *stem* from which arises (c) the long, hollow *cotyledon* whose tip is still within the seed-coat. Remove the testa and observe the colourless end of cotyledon coiled like a watch-spring as it lies within the seed. During germination the cotyledon absorbed the food from the endosperm and passed it on to the growing parts. In older specimens observe how the air-exposed tip of the cotyledon withers; also note the formation of secondary roots from the base of the short stem. Slit open the hollow leaf-sheaf at its base and discover the delicate pale-green plumule within. In still older specimens the plumule itself has split the sheath as a result of its growth and development.



Fig. 23.—Seedling of Pine.

105. Pine.—In a Pine seed notice the 'thin wing for wind-dispersal. Dissect the seed and notice the embryo (consisting of radicle, hypocotyl, numerous cotyledons in a circle around the plumule) surrounded by the endosperm. Sketch the stages in germination (Fig. 23).

106. The Uses of Cotyledons.—From the seedlings you have studied, you will observe that the cotyledons, or first-formed leaves of the young plant, have different functions or uses in different plants. They are always concerned with the feeding of the young root and shoot, but they carry out this duty in different ways. When the seed contains no food stored outside of the young plant, the cotyledons usually contain food. In a few plants—*e.g.* Oak, Broad Bean, Pea—the cotyledons are food-stores and nothing more; they remain below the ground (or on the surface), and simply yield up the food to the growing root and shoot, and are termed “hypogeal” (=below ground). In most non-endospermic plants, however, the cotyledons are carried up into the air and become green, and like all green leaves *manufacture* food (Ch. III.); even in these cases, where the cotyledons are “epigeal” (=above ground), they contain more or less food, though the amount is often scanty—*e.g.* Cress, Mustard—and they have a double function, first supplying stored food and then making fresh supplies. In seeds whose food is stored outside of the embryo, the cotyledons either remain within the seed and act as digesting and absorbing organs, as in Wheat, Maize, Date; or they first digest and absorb the food-store in the endosperm, and then emerge from the seed and become the first green leaves of the plant (Castor Oil, Ash, Onion, Pine).

Plants like Cress, Ash, etc., the embryos of which possess two seed-leaves, are classed under the name *Dicotyledons*, while Onion and Wheat represent the class *Monocotyledons*, as their embryos have only one cotyledon.

Make lists of the various seeds you have examined, arranging them according to (1) the presence or absence of endosperm; (2) the number of cotyledons in the embryo; (3) the hypogeal or epigeal character of the cotyledons; and (4) the nature of the reserve food-substances.

QUESTIONS ON CHAPTER II.

1. How could you prove, by simple experiments, that air is necessary for germination?
2. How can you show that water is essential for the germination of a seed? Why is the young plant in a seed said to be “dormant”?

3. Describe experiments (give methods and results of experiments) which you have made on the absorption of water by seeds.

4. State the composition of air, and the chief properties of its two main constituents.

5. How could you detect the presence of (a) water vapour, (b) carbon dioxide, in the air?

6. How could you prove that a germinating seed respire (breathes), just as a living animal or a human being does?

7. How could you prove that germination does not occur in the absence of oxygen?

8. Why do seedlings grow badly in soil that is too liberally watered? How could you measure and compare the amount of air in different samples of soil?

9. Why should seeds not be planted very deep, nor merely laid on the surface of the soil?

10. How could you prove that warmth is required for germination, and how could you find, roughly, the best (optimum) temperature for germination in the case of some particular plant? What is meant by (a) the minimum, (b) the maximum, germination-temperature of a plant?

11. How could you prove that a germinating seed loses in weight when grown in darkness, that the loss is due largely to the oxidation (or burning) of carbon, and that the cotyledons contain carbon?

12. Compare the food stored in a Bean seed with that supplied to young birds in eggs and to young mammals in milk.

13. What is a carbohydrate? Mention the chief carbohydrates, stating how they are distinguished from each other.

14. What is a proteid? How do proteids differ from carbohydrates? By what simple tests could you detect the presence of a proteid?

15. How are oils and fats distinguished from carbohydrates and proteids?

16. How are the reserve food-substances present in a seed made available for the nourishment of the young plant?

17. What is meant by digestion? How are starch, proteids, and oils digested? To what extent are the processes of digestion similar in plants and animals?

18. How could you measure roughly the work done by a seedling in emerging from the soil? Where does the necessary energy come from?

19. What is the usual appearance of the top of the shoot of a young seedling, and what is the advantage of this? How do seedlings of Maize and Wheat differ from most other seedlings in this respect, and how do they emerge from the soil?

20. What is the difference in structure between endospermic ("albuminous") and non-endospermic ("ex-albuminous") seeds? Show that both kinds of seeds may contain the same kinds of food, and explain why the old terms "albuminous" and "ex-albuminous" often lead students into wrong ideas about seeds.

21. Describe, with sketches, the seed, the mode of germination, and the seedling of the following plants: Pea, Kidney Bean or Scarlet Runner, Oak, Ash, Wheat, Maize, Cress, Linseed, Sycamore, Onion, Cucumber or Vegetable Marrow, Sunflower, Date, Pine, Horse-Chestnut, Castor-oil Plant, Mustard.

22. Write an essay on the uses, and the behaviour during germination, of the cotyledons in the various seeds whose germination you have watched.

23. Enumerate the chief reserve materials of food which are stored in the seeds of plants. Give an example of each, and explain how the embryo or seedling is enabled to utilise the food.

24. Explain why it is that certain seeds—for example, Peas and Beans—split readily when the testa is removed. Name as many other such seeds as you can, and describe in some detail the germination of any one of them.

25. Suppose you had two flourishing seedlings of the same size, and you grew one in the dark and the other in the light. How would each differ from its original weight in the course of a few weeks? If one of them had gained considerably, how would you demonstrate exactly to what the increased weight was due? What other differences would you notice between them?

26. What are the chief points you would emphasise in a lesson on the germination of seeds? What material would you select for the practical work of the class?

CHAPTER III.

THE GREEN PLANT'S NUTRITION.

107. Questions arising from Work on Seedlings.—

The observations you have made on the growth of seedlings must have raised many questions, such as the following. Why does the young main root grow vertically downwards, no matter how the seed is placed? Why does the shoot grow upwards? Why does a seedling remain yellow when kept in darkness and ultimately die, while a seedling set in the light has green leaves and keeps on growing? Is it possible to make a main root turn from the vertical direction which it usually takes? How does growth take place? Where, and how, is the force shown by growing roots and shoots developed? How would the growth of a young Bean-plant be affected if one cut off the cotyledons, or the root, or the shoot? How does the seedling get food when that stored in the seed is all used up?

The only way in which one can gain any real knowledge on these points is to put each question to a living plant and make the plant itself give the answer—in other words, to make experiments. Write down any other questions that occur to you as your work proceeds. In each case keep a record of (1) the inquiry, (2) methods and apparatus used, (3) observations and results, (4) inferences.

108. What are the Chief Functions of the Root?—

Refer to the parts of Chapter I. in which the root of the Broad Bean is dealt with, go over the observations you have made on the roots of seedlings which you have grown, and examine the roots of as many plants as possible, wild and cultivated, pulling or digging them up and examining them as directed in Chapter I. for the root of Broad Bean. What

characters do nearly all roots appear to possess in common, from your own observations on roots of various plants? What do you think are the chief uses, or functions, of roots? How could you test your ideas on this subject by simple experiments? Try any methods that occur to you, before going further.

(a) In a Bean seedling grown in sawdust or soil, cut across the main root just below the cotyledons: the plant falls over. Support the plant by tying it to a stick, and keep the soil or sawdust moist around the cut place: notice the new roots formed from the lower part of the stem.

(b) Repeat (a) with another seedling, planted by itself in a pot or box, but after tying it to a stick allow it to remain *unwatered*. What changes does it show, from day to day, in the colour, shape, and position of the leaves, and in any other respects? How would you describe these changes, and what ultimately becomes of the shoot? For comparison, allow some *uninjured* seedlings to remain unwatered: do they show the same changes? What do these simple observations prove as to the work of the root?

(c) Fix a seedling with its root dipping into water in which some powdered vermilion has been shaken up vigorously. After an hour or two, cut across the root a short distance above the surface of the coloured liquid. Has any of the colouring-matter (which consists of grains *suspended in the water*) entered the root?

(d) Fix a seedling with its root dipping into red ink (colouring-matter *in solution*), and after a time (try several seedlings, and give them different lengths of time) cut across the root, to see how far upwards the colour has spread, and in what part of the root it travels. Also cut across the *stems* of seedlings that have been in red ink for a day or two, and notice the red-stained bundles: how does the liquid travel in the *leaves*?

The root, therefore, fixes the plant in the soil and also absorbs water and passes it upwards through the stem into the leaves. The water absorbed from the soil is not *pure* water; it contains dissolved substances of great importance in the nutrition of the plant, as we shall see later.

Do you know of any plants whose roots have other functions besides those of fixing the plant and absorbing water with dissolved salts? What common plants have (1) roots which absorb water but do not fix the plant in the soil, (2) roots which store up food, (3) roots which enable the plant to climb? Examples are (1) Duckweed, (2) Carrot, (3) Ivy.

109. What are the Chief Functions of the Shoot?—

It is very easy to see that the *stem* of a plant like the Broad Bean has at least two duties to perform—(1) to carry the leaves and keep them spread out to the air and the light, (2) to carry up to the leaves the water absorbed by the root. Stems have other kinds of work to do besides these, as you will see as your observations and experiments continue.

110. How do Plants Feed?—After the seedling has used up the food laid up for it in the seed (in the embryo itself or in another part of the seed), it must, in order to go on living and growing, get food in some other way. From what sources, and by what processes, does the plant obtain food? What substances does the plant need for healthy life and growth?

111. Effect of removing the Cotyledons.—Seedlings grown in darkness lose in dry weight and eventually die (Art. 65); the smaller the amount of food stored in the seed, the shorter is the life of the darkened seedling. Some further experiments will serve to emphasise this point.

Remove one or both *cotyledons* from soaked Broad Beans just beginning to germinate. Place some of these seeds, along with untouched seeds, in the light; place others, also with untouched seeds for comparison, in darkness.

112. Effects of removing Foliage-Leaves.—Remove the *foliage-leaves* from (1) a young Bean-plant which has not yet used up the food in its cotyledons, (2) an older plant whose cotyledons have fallen off (if they have shrunk considerably, but are still attached, pull them off). Does the removal of the foliage-leaves check the growth of the plant, as compared with that of similar plants left untouched? In which case, (1) or (2), is the effect greatest?

113. Comparison of Cotyledons and Foliage-Leaves.—We have seen that the cotyledons of the Broad Bean resemble the foliage-leaves in the fact that branches arise in their axils. By growing a seedling in coloured water it can be shown that the cotyledons have veins, which can also be seen in sections examined with the microscope. It is always a useful plan to tabulate—i.e. to write down in parallel columns—the chief differences between different

plants or different parts of the same plant, as regards their position, form, structure, etc.—and then to find out as completely as possible, by observation and experiment, the *reasons* for these differences. In comparisons of this kind always try to discover whether differences in *structure* can be explained as due to differences in *function*.

Cotyledons.

opposite
small
simple
pale yellow
thick
veins obscure
no stipules
remain below ground
gradually turn smaller
fall off after a time

Foliage-Leaves.

alternate
large
compound
green
thin
veins conspicuous
stipules present
formed above ground
gradually turn larger
remain on a long time

Can you add any further differences? Try, as you proceed with your study of the green leaf and its work, to explain these differences in form, texture, duration, etc., between the cotyledons and the foliage-leaves of the Broad Bean.

Gather and examine leaves of various kinds, living or fallen, evergreen or deciduous, stalked or unstalked, simple or divided (compound). What is there common to nearly all leaves, however they may differ in detail? In what surroundings do you find plants with thick fleshy leaves? Does the general broad and thin form of the leaf-blade suggest anything as to the functions of the leaf? Do most leaves seem to expose as much surface as possible to light and air? We saw that the seed-leaves of Broad Bean and of many other plants contain food, and that if they are removed from a soaked seed which is beginning to germinate, the growth of the young plant is stopped.

114. Do Leaves contain Food?—We have seen that seed-leaves often contain food-materials—*e.g.* starch, proteids, oils. It will be easy to find out whether foliage-leaves contain any of these foods. Let us test them for the presence of starch, by using iodine solution. To do this we must try to remove the green colour.

Boil in water some leaves taken from a Bean seedling, or some other plant with thin flat leaves, which has been growing in the light. The colour does not come out. Place the boiled leaves in alcohol, and notice that the leaves gradually lose their colour, while the alcohol turns green. Try several different plants: in some the extraction of the green substance takes place very slowly, in others (*e.g.* Broad Bean, *Tropaeolum* or "*Nasturtium*," Primrose) much more quickly.* When the leaf is colourless, place it in a saucer and pour dilute iodine solution over it. The depth of colour produced shows roughly how much starch is present. If there is abundance of starch, the colour is nearly black; if little starch, it is bluish; if no starch is present, the iodine turns the leaf brownish (test for proteids).

115. Does the Green Leaf make Starch?—Where does the starch come from? Is it *made* in the leaf? Does it come from the soil? If a plant were set in darkness for some days, would its leaves still contain starch?

Keep a plant in darkness until the leaves no longer show starch when tested with iodine, then cut off several leaves and set them in tumblers or bottles of water; the stalk should dip into the water. Set some in sunlight, the others in darkness, and after two days decolorise and test with iodine the two lots of leaves. Those kept in darkness show no starch, but starch is found in those that have been exposed to light. This means that starch is *made* by leaves when in the light, but not when in darkness.

116. Is Light required for Starch-Making?—The preceding experiments show that starch is found in leaves that have been exposed to light, whilst it is absent from the leaves of the same plant after it has been kept in darkness for a day or two. This suggests (1) that light is required for starch to appear in the leaf, (2) that the starch formed in the light disappears in darkness.

Set some plants—*e.g.* Broad Bean, Primrose, *Tropaeolum*—in pots in darkness for at least a whole day. In the morning take off some of the leaves, decolorise them, test with iodine; they give only a light brown colour, starch being absent. Choose a day with sunshine or good diffused light for these experiments:—

(a) Let some of the leaves on the plant remain untouched.

* Do not *boil* leaves in alcohol; this is dangerous, wasteful, and (if suitable plants are used) unnecessary.

(b) Fix a strip of tinfoil across the leaf, on both sides (above and below); or pin to the leaf two flat slices of cork opposite each other on the two sides; or stitch to the upper side of the leaf a piece of black paper or cloth. The object in each case is, of course, to exclude light from a portion of the leaf.

(c) With a knife or scissors, cut the words "starch," "light," your initials, etc., in capital letters out of a series of card; fasten each card to a broad leaf (a Primrose plant, dug up and grown in a pot, or in a jar of water, answers well), and, after letting the plant stand for a full day in darkness, expose it to light for several hours, then decolorise and test.

In each case expose the plant to light from morning till late afternoon, then take off the leaves which have been treated in these various ways, tying to each a label, decolorise them and test with iodine solution. Make notes of your observations and conclusions as to the conditions under which starch is made by leaves. After being tested with iodine, the leaves may be preserved in alcohol and thus made colourless again, and on being soaked in hot water will again give the starch reaction with iodine. *The same leaves can therefore be used again and again*; starch once formed remains in the leaf when it has been killed by boiling.

117. Is Air needed for Starch-Making?—We have already used a simple device (Arts. 15, 31) for finding out whether any part of a plant contains air and bears openings.

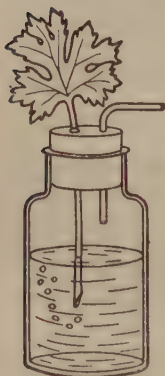


Fig. 24.

(a) Dip the leaves of various plants into very hot (just boiled) water in a warmed tumbler, and notice the expulsion of air-bubbles. In many leaves the bubbles only appear on the lower surface, e.g. Laurel, Rhododendron; in others they appear on both sides, but more abundantly on the lower surface, e.g. Broad Bean. Cut a large leaf (e.g. Laurel) across and dip the cut edge under water, observing the streams of bubbles given off.

(b) Try to blow through leaves dipping into water, first with the stalk and then the blade under water. The simple apparatus shown in Fig. 24 may be used to suck air through a leaf. Suitable leaves are Lesser Celandine, Chinese Primrose, Marsh Marigold, Water Lily.

(c) Even when one cannot force air through a leaf with the lungs, the presence of air-spaces and of openings on the surface can easily be shown by using an air-pump or exhausting syringe to suck air through, or a bicycle-pump to blow air through. The leaf-stalk should be fixed in a bored cork, with another hole for a short glass tube to connect with the syringe or pump by means of rubber-tubing. The cork is fixed into a wide-necked flask or bottle, and the whole made air-tight by means of plasticine and vaseline.

The openings by which the air inside the leaf communicates with the outside air (atmosphere) are called *stomates*, a term meaning "mouths."

(d) Smear the *lower surface* of a leaf with vaseline; this will block the stomates, which in many leaves are mostly or even entirely found on the lower surface. Find out the distribution of stomates on the two sides of each leaf you experiment with by tearing off and examining with the microscope pieces of the lower and the upper skin. If you have no microscope, dipping the leaf into hot water gives a rough idea on this point.

(e) Smear a small circular area of the leaf with vaseline, applying it to *both sides*, so that this part of the leaf will be shut off on both sides from communication with the atmosphere through the stomates.

(f) Smear with vaseline the *upper surface* of another leaf.

(g) Smear *both surfaces* of another leaf.

The results of these simple experiments will show that the air is concerned with the process of starch-making. What about leaves which grow in water, like those of submerged aquatic plants?

(h) In an experiment on germination we prevented the access of air to seeds by covering them with water, and in the preceding experiments we have excluded air by covering the leaf with vaseline. Tie the stalks of the leaves of some ordinary land-plants to a stone and sink them under water in a glass jar. Expose to light, and afterwards test the leaves for starch.

(i) Repeat the last experiment with the leaves of a plant which lives submerged in water—*e.g.* Water Starwort, Canadian Water-weed—or any other plant you find growing below water in ponds or streams. Do these submerged leaves possess stomates?

118. Is Warmth needed for Starch-Making?—It is very easy to find out whether temperature has any influence on starch-production by leaves. Place a leaf in a saucer or jar kept cold by ice, expose to light, and after several hours test for starch.

119. Is Chlorophyll needed for Starch-Making?—Have you noticed, in your experiments with leaves of Broad Bean, Tropaeolum, or Primrose, that the *veins* remain unstained even when the rest of the leaf is black with the iodine-test? This in itself shows that starch is only formed in the green parts of the leaf.

(a) Try variegated leaves (*e.g.* varieties of Geranium or Ivy), making a careful drawing of each leaf before it is decolorised and tested with iodine, and observe that only the green parts produce starch. In leaves whose veins are colourless, or nearly so (*e.g.* Primrose), owing to the absence of chlorophyll above and below them, you will notice that the veins stand out from the rest of the leaf when the iodine-test is applied, by the absence of starch.

(b) Grow seedlings (Bean, Pea, etc.) in darkness, then put them in the light for a day and test the leaves for starch. Leave them in the light until their leaves turn green, then test again for starch.

These results show that the green substance (chlorophyll) is essential for the process of starch-making by leaves.

120. What becomes of the Starch formed in the Foliage-Leaves?—Is it absorbed by the plant, like the starch stored in the cotyledons of the Bean? If so, we ought to find less starch in the leaves in the morning than in the evening, since the leaf cannot make more starch until it is again exposed to light.

(a) Remove some leaves from a plant in the early evening (an hour or two before sunset) and place them in alcohol. Early next morning remove some more leaves from the plant, and also cut out differently shaped pieces from some of the leaves and place them in alcohol overnight; then compare their starch-test with that given by the rest of the leaf the next morning. The starch formed in the leaf during the day is found to have disappeared, more or less completely, in darkness.

(b) Would the starch have disappeared had the leaves not been left on the plant? Repeat the experiment, but cut some of the leaves off, set them in a tumbler with their stalks under water; cut pieces out, test them for starch, then test the rest of each leaf in the morning.

121. How does Starch disappear in Darkness?—We saw that the starch stored in the Bean cotyledons is on germination converted by the action of a ferment (diastase) into sugar, which is soluble in water and therefore able to travel by diffusion to the growing parts of the young plant and supply them with food. We have seen that the leaf when exposed to light produces starch, which disappears during the night, and if we cut out small pieces from the same leaf every day and tested them, we should find that the alternate production and disappearance of starch go on day after day. By cutting out pieces of leaf of a certain area, drying them and weighing, we should find that the dry weight of the leaf is increased at the end of a sunny day, that it decreases after some hours of exposure to darkness, increasing again on exposure to light. These facts suggest that the starch formed in light is digested and carried away during darkness, and we

find that the leaf-cells produce *diastase* just as do the cotyledon-cells in the Bean seedling.

Keep a plant in darkness for two days, then expose it to sunlight for several hours. Remove some leaves, dry them in a slow oven (or on a sand-bath), then powder them and let them soak in cold water for about half an hour. Filter the extract thus obtained, and try its effect on starch-paste, testing with iodine, and later with Fehling's solution. An extract of leaves of *Tropaeolum* or of Broad Bean, made in this way, quickly converts starch into sugar; try these and other plants.

122. How is Air concerned in Starch-Making?—We know from previous experiments that starch can be broken up, by heating it, into carbon dioxide and water, and that carbon dioxide is always present in the air, being produced by all processes of burning when the substance undergoing oxidation contains carbon. We shall see later on that a plant increases in dry weight when grown in a culture solution which contains no carbon, though more than half of the plant's dry weight consists of carbon.

If you consider these facts carefully you will probably conclude that the carbon in the starch made by the leaf comes from the carbon dioxide in the air. Does the leaf in some way make carbon dioxide and water come together to form starch? If so, a plant which is exposed to light and is making starch must be taking carbon dioxide from the air. Again, if the carbon dioxide of the air is the source of the carbon used in starch-making, what will be the effect of exposing green leaves, in light, to air containing no carbon dioxide?

(a) Heat in a dry test-tube (1) pieces of laundry-starch, (2) leaves, (3) pieces of stems, (4) pieces of roots, (5) any other plant tissues. Notice that water is given off as vapour which condenses in the upper part of the tube, and that a black charred mass remains (charcoal, *i.e.* carbon). Fix a J-shaped tube into a cork to fit the test-tube, and let the longer limb dip into lime-water in a bottle or test-tube; notice that carbon dioxide is given off, causing a white precipitate, when these substances are strongly heated. These experiments show that all parts of plants contain carbon, and that starch (the formation of which in plants has been proved in the preceding experiments) also contains carbon.

(b) Put a "*Nasturtium*" (*Tropaeolum*) leaf in a small bottle containing water, so that its stalk dips well into the water while its blade rests on the neck of the bottle. Pour some caustic potash into a wide-necked glass jar, and lower the bottle with the leaf into this jar; then

cork the jar tightly, and smear the edges of the cork with vaseline. The leaf should be taken from a plant which has previously been kept in darkness for two days. The leaf is now exposed to air whose carbon dioxide is absorbed by the potash solution. Set up a control experiment in which the arrangements are the same, but leave the jar open or cover it with a cork (or a piece of wood) in which a hole is bored to admit air.

Use the same apparatus, but, instead of pouring caustic potash into the jar, pass through a hole in the cork closing the jar the tube of a funnel which is filled with soda-lime, or with lumps of caustic potash. This will admit air, but absorb the carbon dioxide it contains. As a control, use a similar apparatus, but place in the funnel gravel instead of soda-lime or potash.

(c) Fit a wide-mouthed bottle with a cork cut in two across the middle. Smear with vaseline the edges of each half of the cork; pour some clear lime-water into the bottle. Then lay the bottle on its side and place between the halves of the cork a primrose leaf of convenient size, so that half the leaf is inside the bottle and the other

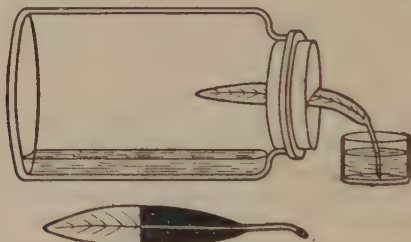


Fig. 25.—Moll's Experiment.

half outside (Fig. 25). The base of the leaf, outside of the bottle, should dip into water in a small dish. See that the halves of the cork are securely sealed with vaseline, then cover the whole apparatus with a large bell-jar, and set it in a good light. After some hours, remove the leaf, decolorise, and test with iodine. If the experiment has been properly arranged, the part of the leaf inside the bottle (*i.e.* in air free from carbon dioxide, which has been absorbed by the lime-water) contains no starch, while the part outside it does. If you do not get this result at first, try the experiment again. This is known as Moll's experiment. Baryta-water or potash may be used.

123. How is the Volume of the Air affected by Starch-Making?—If some living leaves are placed in a closed vessel, how does their absorption of carbon dioxide affect the volume of the air? Does the volume diminish?

Place a few fresh leaves (from a plant which has been previously kept in darkness for a day) in a glass jar fitted with a bored cork through which passes a twice-bent tube (J-tube) and let the outer limb dip into water coloured with red ink in a small bottle, as in Fig. 15. Charge the air in the jar with carbon dioxide as before; cork tightly and seal with plasticine or vaseline. Cause the coloured water to rise a little way in the outer tube, by warming the jar gently and then letting it cool. Mark the level when the preparations are complete, and set the apparatus in good light (not direct sunlight). Does the volume of air in the apparatus (and therefore the level of the coloured water) alter at all? Since changes in temperature affect the level (why?), it is well to prevent draughts by placing a bell-jar over the apparatus, or to set up a control experiment (omitting only the leaves); note the temperatures by hanging a thermometer near the apparatus or passing it through a hole in the cork of the jar. Test the air in the jar for carbon dioxide after a day's exposure to light, by pouring in some lime-water or baryta-water. This experiment shows that **when carbon dioxide is absorbed by green leaves, an equal (or nearly equal) volume of some other gas is set free.**

124. How does Starch-Making change the Composition of the Air?—Have you ever noticed, on a warm sunny day, brisk streams of gas-bubbles arising from plants growing under water in a pond or an aquarium?

Collect some of these submerged water-plants—*e.g.* Water Starwort (*Callitriche*) or Canadian Water-weed (*Elodea*)—and test their leaves for starch. Place them in a large glass vessel (*e.g.* a bell-jar resting on a wooden support); if necessary tie them to a stone to keep them together at the bottom. Are the gas-bubbles given off in darkness? Cover the vessel with a black cloth and see if the bubbling stops after a short time, then expose the vessel to light again. Water-cress or Mint will do, if the plants mentioned cannot be obtained.

What do these bubbles consist of? Is the gas ordinary air, or oxygen, or carbon dioxide? We know that water contains dissolved air, and that this dissolved air is richer in carbon dioxide than ordinary air. Press a glass funnel down on the plants, and either fit a piece of rubber tubing to the tube of the funnel, or, better, invert over the latter a test-tube filled with water, so as to collect the gas given off by the plants. That this gas is **oxygen** can easily be proved by its causing a glowing splinter of wood to burst into flame, or by corking the end of the tube while still in the water, transferring the tube to a vessel containing solution of pyrogallol in caustic potash and opening it, when the gas will be almost entirely absorbed by the solution (see Art. 58).

Keep your water-plants in darkness until the leaves show little or no starch, then transfer them to water which has been boiled (to expel the dissolved gases) and then cooled. Expose them to light, with funnel and test-tube as before. Is any oxygen given off by the plants, and do they make any starch?

125. How is Starch made by the Green Leaf?—This is a difficult question to answer. The processes which occur in a green leaf exposed to light, sufficient warmth, and supplied with water, carbon dioxide, and salts, are somewhat complex. The immense importance of the food-making work of green plants—a process on which the nutrition and therefore the life of all human beings depends—has naturally led to a great deal of research on the subject. The process which we have been calling “starch-making”, is more correctly termed **Photosynthesis** or **Carbon-Assimilation**.

It is sufficient, in an elementary book like this, to say that in *most* plants sugar is formed in green parts exposed to light and supplied with carbon dioxide, water, and sufficient warmth; that starch is usually formed from the sugar as an insoluble reserve-food, to prevent the ill-effects of the accumulation of dissolved sugar in the green cells, the starch being deposited as small grains inside the green grains (chlorophyll-grains or *chloroplasts*); that of the rays which make up white light, the red and orange rays are chiefly concerned in the process; that chlorophyll absorbs these rays, and that probably they are converted into electrical energy, by which the carbon dioxide and water are converted into organic substances; that there are several stages in this process, formaldehyde* being produced before the sugars and probably giving rise to sugars by a process of “condensation.”

126. Chlorophyll.—We have seen that only the *green* parts of plants can make starch—so far as the plants we have experimented with are concerned, at any rate—from carbon dioxide and water. The green pigment (chlorophyll) is a complicated substance, probably containing magnesium and phosphorus in addition to carbon, hydrogen, oxygen, and nitrogen. Its composition doubtless varies in different plants. Chlorophyll is not formed in plants kept in darkness,† nor in the complete absence of iron from the plant's food. If a plant is grown in darkness, it assumes a pale yellowish, sickly appearance. This is due to the fact that a yellowish

* A simple carbohydrate (CH_2O); “formalin,” used as a preservative and disinfectant, is a solution of formaldehyde.

† Chlorophyll is formed in darkness in a few exceptional cases, *e.g.* cotyledons of Ferns, Pines, Sycamore.

colouring matter—etioline—is developed in the chloroplasts instead of chlorophyll. Such a plant is said to be *etiolated*. Of course, a plant grown in darkness must have some reserve store of food-material to draw upon, *e.g.* a potato-tuber developing in darkness. Many examples of etiolated plants will readily occur to the mind of the student—*e.g.* celery, grass covered by a roller or a board. Etiolated plants have the internodes very much elongated or “drawn out.” In this way there is a chance of shoots reaching the light, as, *e.g.*, in seedlings smothered by other plants. In etiolated plants, also, the leaves remain small and scaly, there is a great development of soft tissue and a meagre formation of hard woody tissue. Large leaves would be useless in darkness; we might say, therefore, that the plant devotes all its energy to the formation of long “internodes” which may be of use to it.

A yellowish, sickly condition is also established if there is no *iron* in the food, the plastids being colourless or containing etioline. This condition, due to the want of iron, is called the **chlorotic** condition. It is to be carefully distinguished from the etiolated condition due to the absence of light. As soon as the plant is supplied with a *weak* solution of an iron salt, even if it is only applied to the leaves, chlorophyll is developed. Thus iron is necessary to the formation of chlorophyll, although it does not enter into its composition.

Chlorophyll can be extracted by means of alcohol, ether, chloroform, etc. A solution of chlorophyll is fluorescent—it is green by transmitted light, red by reflected light. When the solution is held against the light and examined with a spectroscope, or placed in the path of a beam of light, which is then passed through a prism, the spectrum shows dark bands, in the red, blue, and violet regions especially; the band in the red is very marked, appearing even if a weak solution is used. These dark bands (also seen on examining a thin green leaf with a spectroscope) are of course due to the *absorption* by the chlorophyll of these rays of light, the other rays being allowed to pass through the leaf. The **absorption spectrum** of chlorophyll agrees roughly with the results obtained by exposing plants to red light, green light, blue light, etc. The green rays are absorbed to a much smaller extent than the rays in other parts of the spectrum. That is,

the leaf reflects and transmits the green rays, which appear to play no part in photosynthesis, while it absorbs the useful rays which are in some way concerned in this process.

(a) Extract chlorophyll from green leaves (*e.g.* Bean, Grass; almost any leaves will do, but leathery ones should be chopped up) by boiling them in water, draining off the water, and covering the leaves with alcohol. Then place the dish containing the leaves and alcohol in the dark; light destroys the colouring matter in the solution. Filter the solution, and place it in a corked bottle.

(b) Notice the colour of the filtered extract by holding the bottle up to the light, and by holding it against a black surface; it is green by transmitted light, red by reflected light. Obtain a continuous spectrum on a screen by fastening on the lens of an optical lantern a card with a vertical slit, and holding a prism in the path of the light. Hold a test-tube of alcoholic chlorophyll-solution against the slit, and notice that the colours in several parts of the spectrum are replaced by dark bands. The most prominent dark band appears in the red part, but if the solution is strong bands will also be seen in other regions of the spectrum. Try the effect of interposing pieces of glass of various colours, or bottles containing solutions of dichromate of potash and of copper sulphate. In each case certain rays of light are stopped, that is, *absorbed*, and the *places of these rays in the spectrum are occupied by dark bands*, that is, by darkness. We see now that chlorophyll absorbs certain light-rays, allowing the rest to pass through it, and we may conclude that these absorbed rays in some way supply the energy which is needed in carrying on the work of photosynthesis. A direct-vision spectroscopic will show the absorption-bands, especially that in the red part of the spectrum. A very useful additional piece of apparatus is a wedge-shaped bottle ("indigo prism") by means of which one can examine different thicknesses of the solution.

(c) Fill three test-tubes with the extract, cork them, and place A in sunlight, B in diffused light, C in darkness. Carefully boil some extract in a fourth test-tube (D), and place it with A in sunlight. Notice, after a day's exposure, that A becomes brown, C is unchanged, while B and D are only slightly changed; the absence of oxygen in D hinders the destructive effect of light.

127. Under what conditions is Chlorophyll produced?

—It is easy to prove that *light* is essential for the production of chlorophyll. Sometimes one can get "chlorotic" plants by omitting *iron* from the culture solution in which seedlings are grown. What other conditions are necessary for chlorophyll-formation?

(a) Grow seedlings, *e.g.* Cress or Mustard, in darkness, then place some of them in a good light, close to a window, and note the time required for the production of a distinct green colour. Place the others

in a dark part of the room, and when they have become green test the leaves for starch. These observations will show that (a) a green tinge, due to formation of chlorophyll, may be developed in an hour, or less, in good light; (b) light too weak for photosynthesis is strong enough for the production of chlorophyll.

(b) Grow in the same pot or box some seedlings of Pine and of Bean or Pea, keeping them in darkness, and compare the colour of the Pine-seedlings with that of the others.

(c) Place some etiolated seedlings (Cress, Mustard, Bean, etc.) in a bottle or small glass jar, cover with a glass plate, and set it in a larger jar half filled with water. Keep the water at 30°C . In a similar apparatus keep some of the seedlings in cool water, or water kept at 10°C ., by adding bits of ice from time to time. Compare the depth of the green colour developed in the two sets of seedlings after an hour or two of exposure to light.

(d) To show that oxygen is necessary for the formation of chlorophyll, fill a test-tube with water, invert it in water, and pass under its rim some etiolated Mustard seedlings. Though exposed to light, the seedlings do not become green, owing to lack of oxygen. Another method is to place heavier seedlings—*e.g.* Bean, Pea—in a glass jar and cover it with water. In each case similar etiolated seedlings should be placed on wet blotting-paper at the bottom of a jar, whose mouth must of course be left open.

128. What is the Function of Chlorophyll?—This is a hard question to answer, except in a very vague manner. We know that the waves of electrical energy, which can produce formaldehyde from carbon dioxide and water, are much longer than the light-waves in the red end of the spectrum and that red light is nearly as efficient as white light in the process of photosynthesis. We know also if a leaf is covered by another leaf, or by a solution of chlorophyll, it manufactures little or no starch.

As a working theory, one might infer, from the known facts, that the function of chlorophyll is to convert light energy into electrical energy, by increasing the wave-length so as to transform the relatively short waves of light into the much longer waves of electrical energy. If this be so, one can understand why the longer light-waves (red) are so efficient in promoting carbon-assimilation.

129. The Food Materials of a Green Plant.—If we make a chemical analysis of a plant—an analysis of the gases given off and the residue or ash left behind on burning the plant—we find the following chemical elements: carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, magnesium, potassium, iron, sodium, silicon, and chlorine; traces of other elements are sometimes present. Of all these elements, only the first six actually enter into the composition of the living substance (protoplasm) of the plant. It is evident

that all the elements found in the plant must enter it in the food materials absorbed. All the carbon required by an ordinary green plant comes from the carbon dioxide of the air, which is absorbed by the green parts of the plant, while the other elements are absorbed by the roots, usually in the form of nitrates, sulphates, phosphates, chlorides, and silicates of potassium, sodium, calcium, magnesium, iron, and other metals.

130. Essential Elements of Plant-Food.—All the elements already mentioned, and several others, occur in the composition of plants and their food. In fact, nearly all the chemical elements known to occur in soil, water, and air have been detected in analyses of plants. It has been found by experiment, however, that for most green plants the **essential elements**—i.e. the elements absolutely necessary for healthy growth—are **carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, potassium, magnesium, and iron.**

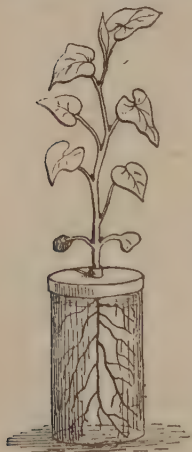


Fig. 26. A Plant of Buckwheat grown with its Roots in a Culture-solution.

131. Water Culture.—It has long been known that a plant can be grown in water containing salts in which all these elements are present with the exception of *carbon*. That carbon is essential is easily proved, as we have seen, yet this element need not be present in the solution supplied to the roots. That all the other elements are essential, and must be supplied to the roots, has been shown by the method of **water culture**. Several plants of the same species are grown in glass jars (Fig. 26), their roots dipping into a culture solution. With most plants there is healthy growth only if the solution contains *potash, lime, and magnesia*, combined with *nitric, phosphoric, and sulphuric acids*, together with a trace of an *iron salt*.

132. Experiments with a complete Culture Solution.—

Get some large glass jars, each holding at least a quart, for water-culture experiments. Sachs' solution consists of 2 grammes of potassium nitrate, 1 gramme each of sodium chloride, calcium sulphate, magnesium sulphate, and calcium phosphate, and a drop or two of iron chloride (or iron phosphate) to 2 litres of distilled water. Knop's solution, which is perhaps better, consists of 2 grammes of calcium nitrate and 0.5 gramme each of potassium nitrate, magnesium sulphate, and potassium phosphate, with iron as before, in 4 or 5 litres of water. Perhaps the best plan is to get 4 oz. of calcium nitrate and 1 oz. each of potassium nitrate (saltpetre), magnesium sulphate (Epsom salt), and potassium phosphate, and powder these salts to make them dissolve more readily. These quantities will be sufficient for 32 gallons of culture solution; but the latter should be made up as required, so that the above quantity of each salt should be subdivided according to the volume of solution required each time.

Grow seedlings of Bean, Pea, Maize, Buckwheat (these answer well, but other plants should be tried, different plants each time you start a series of cultures) until the roots have grown a few inches long, then fix each seedling into a cork or a wooden cover. The cork or cover should have a hole in the centre for the plant, a slit somewhat narrower than the hole running to the edge of the cover (so that the plant can be removed easily when necessary), and another hole for a stick to tie the plant to. Take care to keep the cork, or wooden cover, as well as the part of the plant which is in contact with it, quite dry; most failures in water-culture are due to "damping off" at this part (caused by fungi). If a stick is used to support the plant, there is no need for any packing material; in any case, do not use cotton-wool for this purpose, but soft asbestos which has first been heated and allowed to cool.

Darken the roots by covering the jars with black cloth or paper; add water each day to replace that lost by evaporation (using a funnel, and not letting the cork, or wood cover, get wet). Once a month take the plant out, wash its roots gently in a basin of water, pour out the culture solution, and let the plant remain with its roots in plain water for two days before placing it into fresh culture solution.

133. Experiments with incomplete Culture Solutions.—

Choose seedlings as nearly equal in size and general growth as possible, then place some in a complete solution, others in a solution from which one or other of the essential elements is wanting. To deprive the plant of potassium, use sodium nitrate instead of potassium nitrate, and calcium phosphate instead of potassium phosphate. Deprive others of calcium by omitting the calcium nitrate; of phosphorus by omitting the potassium phosphate; of magnesium by using calcium sulphate in place of magnesium sulphate; of sulphur by using magnesium chloride instead of the sulphate; of nitrogen by using sodium chloride and calcium sulphate in place of calcium and potassium nitrates; of iron by omitting the iron salt (which should be added in all other cases). The culture solution should not be alkaline, or the

roots suffer; if it turns red litmus to a blue colour, add acid (*e.g.* phosphoric acid) until it gives an acid reaction. The roots should be supplied with air; the simplest plan is to force air into the solution every day or two with a bicycle-pump or a condensing syringe.

134. Essential Soil-Substances.—A soil must contain the same essential elements as the full culture solution, in order to allow plants grown in it to come to maturity, and these elements must be in a form available for use by the plant. Soil-water contains most of the essential elements in the form of dissolved compounds. The composition of the water present in a soil can be learned by analysis of drainage water, and we can test soils for soluble substances by letting distilled water drain through them and then applying to it tests for the essential elements given above.

(a) Compare the growth of seedlings (of the same kind of plant) which have been supplied with (1) distilled water; (2) tap water; (3) culture solutions (some complete, others with one element or other omitted in each case). If you grow the plants in washed sand, water with (1), (2), or (3) daily. In either case compare also with plants grown in good garden soil. After, say, six weeks, dry thoroughly and weigh the seedlings, and compare their dry weights; then burn them and compare the ash weights.

(b) Dissolve a small crystal of saltpetre in a little water in a test-tube; add a few drops of diphenylamine sulphate, then pour into the tube a little strong sulphuric acid, and notice the deep blue colour produced. This is a useful and delicate test for nitrates.

(c) Place some dry, fine garden soil in a funnel, plug the tube lightly with cotton wool, and pour water slowly on the soil. Collect the first few drops that ooze through and repeat the test with diphenylamine. A fertile soil always contains nitrates.

(d) Continue to pour water through the soil in the funnel, and after collecting what comes through, evaporate it to dryness and compare the residue with what is left after evaporating an equal volume of the water used.

135. Formation of Nitrogenous Substance.—The elaboration of nitrogenous substance is not so clearly understood as that of carbohydrates. Perhaps the simplest process, leading to the formation of soluble nitrogenous compounds (*amides* or *amido-acids*, containing carbon, hydrogen, oxygen, and nitrogen), that one can suggest is the inter-action of sugar and nitrate of potash, the chief products being an amide called asparagin (widely distributed in plants) and oxalate of potash.

The latter, like oxalic acid itself, is poisonous, but it combines with the lime brought up in salts from the soil, forming oxalate of lime, which is insoluble in water, and therefore crystallises out and is

rendered harmless. This is probably one source of the oxalate of lime which occurs so abundantly in crystals in plant-tissues. These crystals are more abundant in leaves exposed to full sunlight than in shaded leaves, and in the green than in the not-green parts of variegated leaves.

The disappearance of nitrate from leaves shows the same relation to light and to the presence or absence of chlorophyll as does the accumulation of oxalate of lime; the test for nitrate is given in Art. 134 (b). Nitrate disappears from cut leaves in a few days, if they are exposed to light; in variegated leaves the nitrate disappears only from the green parts.

136. Formation of Proteids.—Thus we have explained, as far as possible, the building up of soluble carbohydrates (sugars) and soluble nitrogenous compounds (amides) in the green leaf. With the exception of what is used directly by the assimilating cells, the sugars and amides are transferred to the various parts of the plant. All living cells contain these soluble carbohydrates and nitrogenous compounds conveyed to them in the cell-sap. The living protoplasm makes use of these as food substance. Together with sulphur and phosphorus they are built up first of all into more complex (*proteid*) substances, and, finally, into protoplasm. This final elaboration is most active where rapid growth is taking place, *i.e.* at growing points.

One of the chief forms in which sulphur enters the plant is calcium sulphate. The sulphur is liberated, and thus enabled to combine with the organic food substance, by the action of an organic acid. This acid appears in many cases to be oxalic acid. The calcium of the sulphate combines with the oxalic acid to form calcium oxalate.

137. The Main Function of the Leaf is to act as a laboratory for the manufacture of organic food from the carbon dioxide of the air and from the water absorbed by the roots. To carry out this process energy is necessary, and this energy is supplied by the light which the green chloroplastids absorb. During the process more complex substances such as sugar are formed, and a corresponding amount of energy is stored up in this manner. At the same time a volume of oxygen gas is liberated, equivalent to the amount of carbon dioxide assimilated. Hence green plants exposed to sunlight tend to purify the air rendered foul by the breathing of animals.

When a plant is burnt, oxygen is consumed and mainly carbon dioxide and water produced, while the stored energy is liberated again almost entirely in the form of heat. This energy was stored up in latent form during the assimilation of carbon dioxide, and it really represents that portion of the

sunlight absorbed by the plant, which was utilised in the process, and which provided the energy necessary to produce a chemical change of this kind. Coal consists of the remains of plants of past ages, and hence, when a piece of coal burns, the heat and light which are liberated simply represent so much sunlight which has lain dormant for millions of years.

Enormous quantities of carbon dioxide are absorbed by green leaves from the air, although the latter usually contains not more than 0·03 to 0·04 per cent. of this gas. A large Sunflower leaf may absorb, during a single hour's exposure to sunlight, the carbon dioxide contained in many cubic feet of air, and almost the whole of this enters the leaf through the stomates. The leaf is an organ especially adapted for rapid gaseous exchange.

About half of the dry weight of a plant consists of carbon, and the 4 litres of carbon dioxide contained in 10,000 litres of air contain only 2 grammes of carbon. A tree having a dry weight of 5,000 kilograms must therefore (to obtain its $2\frac{1}{2}$ million grammes of carbon) deprive 12 million cubic metres of air of their carbon dioxide. The actual supply of carbon dioxide in the air is estimated at 3,000 billion kilograms, containing 800 billion kilograms (about 800 million tons) of carbon, which would be sufficient for the earth's vegetation for several years, even if the supply were not being continually renewed by the respiration and decomposition of organisms, by processes of burning, etc.

Green plants when exposed to light and supplied with carbon dioxide can live, grow, and produce flowers and seed, if they are also supplied with water and with the inorganic salts present in the soil. From these simple substances they are able to construct the whole of the food materials they require, and a large tree may produce some hundredweights of organic substance each year in this manner, although only a fraction of this food is used for constructive purposes or as storage material, the remainder being consumed in respiration.

138. Respiration.—Every living being, plant, or animal needs a continual supply of energy, without which, for example, neither growth nor active movement is possible. In the case of a machine, such as a steam-engine, this energy

is derived from the burning of coal, the carbon of the coal being oxidised to carbon dioxide, and energy being liberated in the form of heat. Similar processes take place in all living beings, but here the combustion is less violent, so that the rise in temperature is never very great, and the substances consumed may be more or less complex in character (starch, oil, proteids, etc.).

Like animals, all plants respire—that is, they absorb oxygen and exhale carbon dioxide—losing carbon during the process. Germinating seeds and fungi respire as actively as do warm-blooded animals. The process of respiration is one of slow combustion, and, although the carbon is oxidised at a comparatively low temperature, enough heat is produced to keep an animal warm, or to raise the temperature of a plant by a few degrees. Plants have, however, so large a surface relatively to their bulk that they lose heat very rapidly, and are usually at almost the same temperature as that of the surrounding medium.

When a green plant respire it simply consumes organic material, which it itself had previously constructed from simple compounds by the aid of the energy contained in sunlight. Thus starch is produced from water and carbon dioxide, and a certain amount of energy fixed and oxygen liberated. Then, at a later date, starch may be consumed in respiration, oxygen being absorbed, carbon dioxide and water liberated, and the “fixed” energy set free. Green plants are unable to make direct use of the energy of sunlight they absorb, but, instead, adopt this apparently roundabout method. Its utility is, however, sufficiently obvious, for if plants were directly dependent upon the radiant energy of the sun for their supplies of energy, they could only grow during the daytime, and even then the more deeply situated tissues would receive hardly any supply of energy as compared with the more external ones.

Photosynthesis and respiration are therefore, to a certain extent, antagonistic processes, the first involving a production of organic material, a consumption of carbon dioxide, and a liberation of oxygen; the second, a consumption of organic material, a liberation of carbon dioxide, and a consumption of oxygen. The former process is twenty or thirty times more active than the latter in most healthy green organs exposed

to bright light and supplied with sufficient carbon dioxide, so that these parts do not appear to respire during the day-time, or at least do not evolve any carbon dioxide. In darkness, however, it can be shown that they respire only, as is the case with roots and all other not-green parts in both light and darkness. The following experiments illustrate these points:—

(a) Place a bunch of roots, or some carrots or onions sliced in half, or twenty to thirty germinating peas, in a jar, and after a day or two lower a lighted taper into the jar; what occurs?

(b) Repeat the foregoing experiment with similar materials; place one jar in light, another in darkness. After a day or two pour in some lime-water or baryta-water, which will become quite milky, showing that carbon dioxide has been evolved in abundance. The same occurs when the bottles are exposed to bright light, as respiration continues almost unchecked.

(c) Suspend three healthy laurel leaves by threads from the well-fitting cork of a large bottle containing lime-water, and expose them to bright light. After several hours the lime-water is still comparatively clear. Cover the bottle with black cloth, and in a few hours the lime-water will become quite milky, owing to the respiration being no longer masked by the re-assimilation of the carbon dioxide it produces.

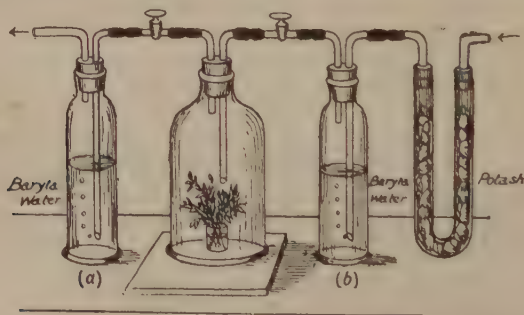


Fig. 27.—The Arrows show the Direction of the Current of Air, which is drawn through by attaching an "Aspirator" at the left of the Apparatus.

(d) Place some green leaves in a glass jar (Fig. 27), through which a slow current of air is passed. This air is deprived of its carbon dioxide by the potash contained in the first tube, so that the lime-water or baryta-water in both (a) and (b) remains clear so long as the leaves are exposed to sunlight or very bright daylight, whereas if the

bell-jar is covered with a black cloth, the liquid in (α) soon becomes turbid and milky.

139. The "Balance of Nature."—Animals and non-green plants are all ultimately dependent upon green plants for their organic food. Even the lion, which devours herbivorous animals, feeds on grass at second hand. In order to obtain a sufficient supply of energy, without which life is impossible, the greater part of this food is consumed in respiration, the carbon being re-oxidised into carbon dioxide, which is ultimately again assimilated by green plants.

The whole series of these interchanges between the self-supporting (chlorophyllous animals and plants) and the dependent members (non-green animals and plants) of the organic world forms what is known as the "Balance of Nature." If more organic food becomes available animals and non-green plants tend to increase, and hence produce larger quantities of carbon dioxide, which favours the development of green plants. The increase in the number of animals is automatically checked by the limitation of the supply of food. A variety of other factors operate in maintaining the balance of nature, and it does not seem to have varied to any great extent since the coal age, millions of years ago.

140. Structure of the Leaf.—A fuller knowledge of the structure of the leaf will help us to understand its functions better. Even if you have no microscope, you can learn a good deal about leaf-structure.

(α) The following is a good method of examining the structure of a leaf. Boil some small entire leaves (those of Box or Privet answer well) in caustic potash for about ten minutes. Hold a leaf under water, and with scissors cut off a strip round the margin; the leaf is then readily separated, with the aid of a mounted needle, into three parts, which should be mounted on separate slides and examined with the lens, and then covered with a cover-glass and examined with the microscope. The three parts are (1) the upper skin or epidermis, (2) the middle tissue or mesophyll, containing the veins, (3) the lower skin. The upper and lower skins are thin and transparent, each one cell in thickness; they are, of course, continuous with each other at the edge of the leaf. In the upper skin all the cells fit closely together without any spaces between them, but in the lower skin there are numerous openings (stomates). Tease the middle tissue with needles, so as to separate the cells in one portion; notice the shapes of these cells, some being cylindrical, others branched. You will probably find some of the cylindrical cells still attached to the inside of the upper skin, and some of the branched cells inside of the lower skin.

(β) Fold a large leaf (*e.g.* Laurel or Rhododendron) several times, and cut thin sections, keeping the razor wet with alcohol. Mount in water, examine with a microscope, and sketch a thin part. Cut some sections with the razor dry, and mount in water; notice the presence of

numerous irregular air-bubbles between the cells of the spongy tissue, then run in some alcohol and observe the expulsion of most of the air in the form of spherical bubbles. This shows that the spaces between the cells of the spongy tissue contain air. How did this air get in? Examine thin sections and try to find stomates leading into the air-spaces.

(c) Strip off a piece of the lower epidermis (Broad Bean, Narcissus, Arum, and Ivy-leaved Toadflax answer well), mount in water, and examine with the microscope. Notice the stomates (are they open or closed?) and the presence of chlorophyll-grains in the guard-cells (do they occur in the other cells of the epidermis?). Find an open stomate with the high power, put a drop of 3 per cent. salt solution at one side of the cover-glass, and draw it through with blotting paper. Notice the effect of this on the stomate. Now put a drop of water at one side and draw it through, until the stomate opens again. Sketch the stomate opened and closed. The salt solution draws water out of the guard-cells, and then the stomate closes as the guard-cells lose their turgidity and collapse. When water is added, the guard-cells absorb it and swell up, becoming turgid, and the stomate opens.

(d) Cut sections of leaves that have been exposed to light for several hours. Examine some sections to see what parts contain the green grains, then treat others with alcohol and test with iodine. Notice that starch-grains occur only in cells which contain chlorophyll. Tear off bits of the upper and lower epidermis-layers, and notice that only the guard-cells of the stomates contain starch. The starch-grains are very small and are formed inside the chlorophyll-grains.

The leaf (Fig. 28) is covered externally by a layer of flattened cells (skin or *epidermis*), and the outer walls of these skin-cells are chemically changed, the cellulose being *cutinised* by the addition of a substance (cutin) which is almost impermeable to water and gases. This substance, which resembles cork in some respects, is most abundant in the outer part of the cell-wall, so that the epidermis is covered by an outer sheet or **cuticle**. The cuticle acts as a protection against drying; it is especially well developed in plants that grow in exposed situations and in "evergreen" plants, while it remains undeveloped in plants which grow submerged in water.

The epidermis is discontinuous at certain points, leaving narrow oval apertures called **stomates**, each of which is surrounded by a pair of special curved guard-cells. The latter are able to open or to close the stomates, for when they are quite tense (*turgid*) they curve apart, but when less so, they collapse and come together. The stomates are very minute but extremely numerous, and in *bifacial* leaves which

have distinct upper and lower surfaces, they are usually more abundant on the lower surface.*

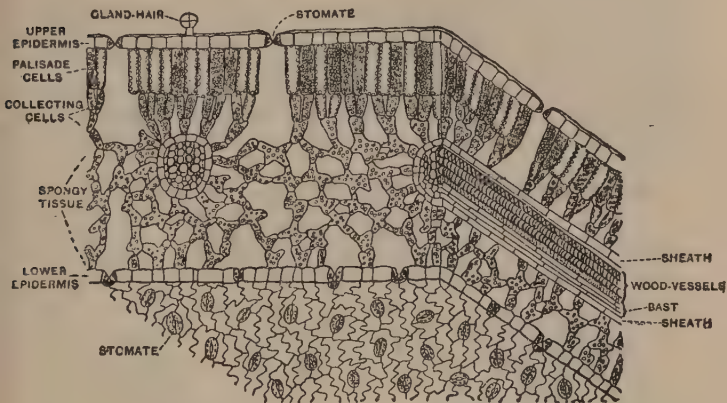


Fig. 28.—Structure of Part of a Broad Bean Leaflet.

The centre of the leaf is occupied by ground tissue, through which strands of conducting tissue run, the latter being the "veins" of the leaf. In bifacial leaves the ground tissue (*mesophyll*, or central-leaf tissue) is usually divided into an upper region in which its cells are long and narrow in the vertical direction (*i.e.* lengthened at right angles to the surface of the leaf), and a lower region in which the cells are branched and loosely arranged. The upper tissue (palisade tissue) is compact, the cells being close together or separated only by narrow spaces, whilst the lower tissue (spongy tissue) contains large spaces between the cells. The cells of the palisade and spongy tissue all contain green grains; so do the guard-cells of the stomates, but not the other cells of the epidermis, nor those making up the veins.

* A square millimetre of Broad Bean leaflet gave, as the average of several countings, 90 stomates in the upper epidermis, and 140 in the lower; a leaflet with area 10 sq. cms. therefore bears over 200,000 stomates.

It is easy to discover that the spaces between the cells of the middle tissue of the leaf contain air, and that they communicate with each other throughout the leaf, with the air-spaces in the corresponding tissue (ground tissue, cortex) of stem and root, and with the external air by means of the stomates. The green grains (chloroplasts) present in the middle tissue (mesophyll) and in the guard-cells contain chlorophyll, which can be dissolved out of the grains, leaving them colourless.

141. Transpiration.—Everyone knows that a leaf, plucked from a living plant, becomes dry and withered after a time. A Bean seedling becomes limp when pulled up and allowed to “wilt,” but recovers when set in water.

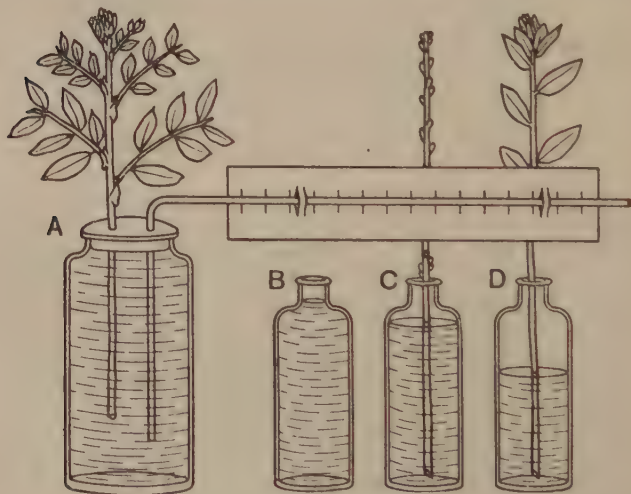


Fig. 29.

Have you noticed that wherever plants are enclosed by glass—*e.g.* in greenhouses, or bell-jars covering plants—moisture often collects on the glass? Does this moisture come from the moist earth, or from the plants, or from both?

It is easy to show by experiment that a healthy and vigorous plant gives off water-vapour, which escapes chiefly from the leaves. This escape of water-vapour from a plant is called *transpiration*, and the current of water which passes from roots to leaves is called the *transpiration current*.

Get three similar bottles full of water (Fig. 29, B, C, D). Into one (D) place a leafy shoot, into the second (C) a shoot deprived of leaves, and leave the third (B) as a control. See that the level of the water is the same in all three bottles at first; after some hours' exposure to light compare the amounts of water left in the bottles. Which loses most water, and which least?

142. Transpiration Experiments.—Does the water-vapour escape from both sides of a flat (bifacial) leaf to an equal extent? Through what channels does it pass in the leaf? Does the rate of transpiration vary, and what conditions cause it to vary?

(a) Fix a long-stalked leaf (or the upper part of a Broad Bean or shoot, *e.g.* Dead Nettle) in a card, passing the leaf-stalk (or the stem) through a hole in the middle of the card and sealing it up with putty or plasticine. Place several cards, each with a leaf or shoot fixed into it, over tumblers nearly filled with water, and over each of these tumblers invert a dry empty tumbler, resting on the card. Notice the drops of water formed on the inside of each empty tumbler, by condensation of the water-vapour given off by the leaves. Ascertain whether any water-vapour is given off when (1) the upper surface, (2) the lower surface, of the leaf is smeared with vaseline to block the stomata.

(b) Get any leaves with broad, thin blades and fairly long stalks—*e.g.* Lesser Celandine, Garden Geranium.* Place them in bottles of red ink, with the cut lower end of the stalk dipping into the ink, and note the coloration of the veins. Cut a Grass shoot above the creeping stem, and try the same experiment, noticing the parallel arrangement of the veins, as indicated by the red lines which appear in the leaves in a day or two; a maize or wheat seedling may be used.

(c) The sucking force exerted by the leaves can be demonstrated by attaching a leafy branch, cut under water, to a tube filled with water and dipping into a coloured solution. It will be found that the latter ascends the tube even when the latter is many feet in length.

Get a branch of Willow in which the young leaves have become fully expanded, and attach it by means of a piece of stout indiarubber tubing to a glass tube about 9 ins. long, with the end farthest from the branch bent at right angles for about 2 ins. Arrange the branch

* In winter the long-stalked heart-shaped leaves of Hedge Mustard are very useful for experiments on transpiration.

vertically, the longer limb of the glass tube horizontally, and the short terminal part dipping into water tinged with red ink. It is best to cut the branch and attach the tubing under water in a large basin, so as to prevent the entrance into the stem of air-bubbles, which would diminish the flow of water. Lift the glass tube out of the water when the branch is fixed up, and notice that the coloured water soon begins to travel along the horizontal tube. This apparatus may be used to roughly measure the rate of the transpiration current. Ascertain whether the flow is different on bright and on dull days, and whether it is influenced by opening door and window so as to cause a draught.

What is the effect of smearing the surfaces of the leaves with vaseline? On different branches, smear (1) the upper surfaces, (2) the lower surfaces, (3) both surfaces, of the leaves, and note the rate of the transpiration current in each case.

(d) For experiments with small plants (*e.g.* Bean seedling) or even single leaves the apparatus sketched in Fig. 29 A is convenient. The rate of flow is roughly measured by the paper scale fastened to the long horizontal tube; care must be taken to make the cork and the joinings of plant and tube with it air-tight by using plasticine or wax.

(e) By the aid of a simple piece of apparatus (Fig. 30) and a weighing balance, the amount of water lost by a leafy stem can be determined, and at the same time it can be proved that the amount transpired is approximately the same as that absorbed by the roots. A plant is fixed by means of an air-tight indiarubber cork in a bottle filled with water. As water evaporates from the leaves and is absorbed by the roots, the level of the water in the graduated tube falls. This gives the amount absorbed by the roots, and on weighing the apparatus it will be found to correspond to the total amount lost by evaporation from the leaves and stem. Each of the larger divisions on the graduated tube corresponds to a cubic centimetre of water, so that when the roots have absorbed that amount the entire apparatus will have lost about one gramme in weight. The vertical tube attached to the side of the vessel, if not graduated by engraved lines,

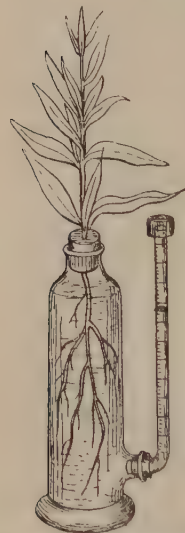


Fig. 30.—Apparatus for estimating the Absorption of Water by the Roots, and the Loss by Evaporation from the Leaves.

may have a scale drawn on a narrow strip of paper and fixed to it. The divisions should represent definite volumes, such as cubic centimetres. Fill the vessel with water, replace the stopper firmly, and set aside for observation. The volume of water becomes less, and the amount of loss may be seen by observing the scale. Enter in a book the amount of loss in equal intervals of time, and note that it is less during darkness than in the light, and also that it varies with atmospheric conditions.

(f) Fix a Wallflower or large Bean seedling in the apparatus shown in Fig. 30, and determine the amount of water lost under the optimal conditions (*i.e.* in a warm, airy, well-illuminated room), either by weighing at intervals, or by watching the attached register. Then remove all the leaves and cut out twice their area in thick note-paper, to which add a piece the same length as the stem and three times its breadth. Weigh all the pieces of paper together, and also a piece a foot square. The former weight divided by the latter will give the approximate surface area of the plant in square feet. From these data the average amount of water evaporated in a given time from a square inch of surface can be calculated.

(g) Another method is to use a small plant, *e.g.* a garden Geranium, growing in a tin fitted with a split cork through which passes a tube for watering. Make water-tight with plasticine, and note the loss of weight. Set beside the plant a vessel, *e.g.* a saucer containing water, and in order to compare the loss of water from the plant and from an equal area of water determine the area of the transpiring surface and that of the water in the saucer.

Cut three healthy leaves of Indiarubber plant or of Rhododendron, plug the cut ends with plasticine, cover the *lower* surface of one (A) with vaseline, cover the *upper* surface of the second leaf (B) with vaseline, and leave the third (C) untouched except for the plug over the cut end. Tie a piece of wire or string to each leaf, weigh each leaf carefully, then hang them up near each other and weigh them each day. After several days the leaf whose stomates are blocked (A) will be still green and fresh, while the others will be more or less withered and brown.

(h) Get some **cobalt chloride** (nitrate or sulphate); make a solution (about 5 per cent.) in water, and soak some filter-papers or sheets of thin blotting-paper in the solution. Dry the papers, and observe that they turn blue. Put a drop of water on one of the dried papers, or simply breathe on it, and notice the change in colour. These cobalt-papers afford a delicate test for water-vapour. Place a thin leaf between two cobalt papers, and keep them flat by placing between two dry pieces of glass. Notice which surface of the leaf gives off most water-vapour, as shown by the change of colour.

143. The Transpiration Current.—The amount of water conveyed upwards from the roots to the leaves is often very great, the water flowing upwards at from 6 ins. to 6 ft. per hour in trees.

If the stem of a Vine or similar plant is cut in spring, large quantities of watery sap escape from the cut end attached to the roots,* and if a tube filled with mercury or

* This only takes place when the plant is fully charged with water. Hence, in summer, no "bleeding" is shown, although if all the leaves are removed it may commence after a longer or shorter interval.

water is attached to this cut end, by stout rubber tubing, the escaping sap may support a column of mercury several inches high, or one of water several feet in height.

At night the stomates close and transpiration is very much diminished. Absorption by the roots continues, however, and frequently so much water accumulates in the leaves that drops are forced out from them. Drops of water may often be seen in the early morning on certain Saxifrages and Grasses, and a similar exudation of water may be artificially induced by forcing water under pressure into a leafy branch.

A Sunflower, $3\frac{1}{2}$ ft. high and with a surface of 5,600 square ins., has been found in summer to exhale a pint of water a day, which is about a cubic millimetre from each square inch. Excessive and unchecked transpiration is, however, highly dangerous, and hence arises the importance of an impermeable cuticle, for it allows transpiration to be regulated by the opening and closing of the stomates.

The guard-cells collapse and close the stomates in darkness, and also where there is a deficient supply of water, or when transpiration is too active. The leaf is unable to assimilate carbon dioxide in the absence of light, so that the stomates may close in darkness without detriment to the plant, and in this way unnecessary evaporation and its accompanying cooling effect are largely avoided.

Probably two causes at least are responsible for the upward flow of water, which of course takes place against the action of gravity. In the first place the evaporation from the leaves tends to suck fresh supplies upwards to replace that removed by the air in the form of water-vapour, and in the second place the roots and stem seem to exercise a pushing force, driving water upwards. Experiments with leaves or shoots cut off and set in water prove that the leaves *draw* water upwards. How can we find out whether water is *forced* upwards by the root?

(a) Choose a healthy Bean seedling growing in soil in a pot, and cut across its stem about 3 ins. above the soil. Tie a bit of stout rubber tubing, a few inches long, on the stump, and fill this tube with water, then tie into the rubber tube a glass tube of fine bore (capillary tubing). Support the glass tube horizontally by means of a cleft stick; squeeze the rubber tube so as to force some water out of the end of the glass tube and absorb it with blotting-paper, then release the rubber tube so that air is drawn into the glass tube. Watch the advance of the water

(which should be coloured with red ink) along the glass tube. Try this experiment with vigorous plants of various kinds growing in pots.

(b) Cut off the stem close to the ground, and connect the stump to a long, straight piece of glass tubing; lash this tube to a stick placed in the soil, pour a little water into it, then a drop of oil, which will float on the water and prevent evaporation. Measure the ascent of the water in the tube, and find out how the rate is affected by temperature.

144. Root-Hairs are developed on roots a short distance behind the root-cap. They soon die away from the older parts of the root. They come into very close contact with the earthy particles, so that when the root of a seedling is lifted from the soil, a portion of the latter adheres wherever root-hairs are present (Fig. 31), but not where they are absent. The surface of the root is increased at least fifty or sixty times by the root-hairs. The root-hairs come into contact with the water around the soil-particles, and each hair becomes surrounded by a film of water. Some roots contain sugar (Carrot, Beet, Parsnip, etc.), and by chemical tests we always find in roots sugar or other substances that are capable of "attracting" water. We have here the conditions under which *osmosis* occurs—two solutions separated by a permeable membrane (cell-wall of root-hair), and we may infer that soluble substances in the soil-water diffuse into the root-hair, while some of the substances dissolved in the cell-sap of the root-hair diffuse into the soil.

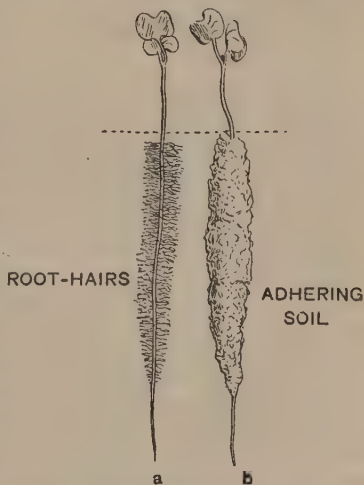


Fig. 31.—Mustard Seedlings grown in Sand.
a, Has been gently shaken in water.

Root-hairs are especially well seen on the roots of seedlings (Figs. 9, 21, 22, and 31). In seedlings of Wheat, Radish, Turnip, Cress, or Mustard, grown on muslin stretched over a tumbler of water, the hairs are very abundant. An even better method is to place the seeds in an

earthenware dish, or on pieces of brick or broken plant-pots, and keep them moist, covering them with a sheet of glass or a bell-jar; the root-hairs are freely developed in the damp air, forming a white fleecy covering on the roots.

Make a rough model of a root-hair out of a long potato-tuber. Cut off one end of the tuber so that it will stand upright, and with a knife scoop out the middle part, leaving on the outside a layer about a quarter of an inch thick. Half fill the tuber with salt solution or sugar solution (about 5 per cent. in each case), coloured with red ink, and stand it in a dish of water, the level of which should not exceed that of the salt or sugar solution inside the tuber. From day to day observe the rise of the coloured solution, showing that water has been absorbed from outside.

145. How is Root-Pressure set up?—The process of osmosis through the thin cell-wall of a root-hair is largely influenced by the layer of living substance (protoplasm) within the cell-wall, which allows only weak solutions to pass into the hair, and which retains the water in the cell-sap at a high pressure. The tense condition of the root-hair thus set up is called turgidity. It is really osmotic pressure, regulated by the influence of the living protoplasm layer. If the "artificial root-hair" is placed in a solution stronger than that which is inside it, water is drawn out. Exactly the same occurs with the real root-hair. Its stiffness or turgidity is, like the stiffness of an inflated bicycle-tyre, due to the pressure inside it. This pressure in the root-hair is due to absorption of water—hence, when we draw this water out the root-hair collapses or becomes flaccid. The presence of salts in large amounts in soil-water hinders absorption by the root; this is exactly what the root has to endure in salt-marshes and peat-bogs.

When the pressure thus set up in the root-hair reaches a certain point the protoplasm of the root-hair undergoes a change, so that it allows the cell-sap to be forced into the cells of the cortex at the base of the root-hair. Each cell in turn, as we pass inwards in the cortex, repeats this process, alternately becoming turgid and collapsing, so that the water with dissolved salts eventually reaches the central cylinder, and is forced into the wood-vessels.

The effect of the millions of root-hairs absorbing water and passing it on to the cortex-cells, which pump it into the vessels, is to produce considerable pressure, which we may regard as a force driving the water into the wood-vessels and upwards. In some plants it is very marked, especially in spring; but it can be demonstrated in most plants while active growth is going on and there is sufficient water in the soil. Many plants "bleed" when cut; this is often seen in trimming or pruning plants, especially in spring or early summer.

146. Summary of Chief Functions of the Green Leaf.—These functions may be thus briefly summarised:—

(1) Leaves are the respiratory organs of the plant, since they allow a free exchange of gases with the atmosphere by means of their stomates.

(2) The chlorophyll of the leaf, which, as we have proved, is itself formed only under the influence of light, has the power, under this same influence, of decomposing the carbon dioxide of the atmosphere, and of building up with the carbon so obtained, together with the dissolved mineral substances absorbed by the roots from the soil, the sugar, starch, and other organic compounds of the plant. Some of the material thus formed in the leaves is transmitted to the stem and root in a soluble state, and often stored in these organs in large quantities.

(3) Water absorbed by the roots passes up the stem to the leaves, where a large proportion of it is lost by evaporation through the stomates. Water lost by evaporation in this way is being continually replenished by the roots, and thus there is a steady upward current by means of which new mineral matter is constantly supplied. The stomates are reduced in size by the collapse of the guard-cells when transpiration is too active, and when the water supply in the soil is deficient. They also close in darkness, when less food is needed; and by so doing they also prevent the plant from becoming too cold, for evaporation is always accompanied by a reduction in temperature. In brief, therefore, the leaf primarily acts as an organ for absorbing radiant energy, and storing it up as potential energy in the form of food. It also promotes gaseous exchange in general, and usually forms the main transpiring surface, although transpiration, like respiration, is one of its subsidiary functions.

147. Adaptation of the Green Leaf to its Functions.

—It is interesting to note how the structure of the ordinary bifacial type of foliage-leaf is adapted for the work it carries on.

Its flattened form and its position are the most favourable for absorbing carbon dioxide and for catching light. The epidermis and cuticle prevent excessive evaporation, besides acting as a screen against undue heating and other ill-effects of strong light. Both palisade and spongy mesophyll cells, containing numerous chloroplasts, are adapted for assimilation. The palisade tissue is adapted to protect the chloroplasts from the effects of too bright light; when the light is diffused, the plastids are arranged chiefly along the upper

and lower walls of the columnar palisade cells, but in strong light the protoplasm moves in such a way as to arrange chloroplasts along the side-walls of the cells with their edges (the chloroplasts are disc-shaped) presented to the light. The spongy-tissue, with numerous air-spaces communicating with the atmosphere by means of the stomates, is equipped for carrying on the gaseous exchanges concerned in respiration, photosynthesis, and transpiration.

The spreading veins, the larger ones projecting on the lower side of the leaf, while the smaller ones run between the palisade and spongy mesophyll, carry water (with dissolved salts) to the mesophyll cells and elaborated food (sugar, etc.) from them. The mesophyll cells are arranged more or less definitely in groups extending from the epidermis to the veins; this is clearly seen in most leaves with well-marked palisade mesophyll, the cells of the latter being arranged in a fan-like manner as seen in vertical section (see Fig. 28), and the cells which converge towards the veins have been called "collecting" or "converging" cells. The veins also serve in the best way to support the leaf; this supporting function is discharged especially by the larger veins, which have bands or cords of hard fibrous tissue below or above, or in both positions.

For a historical summary of the growth of knowledge of the work of the green leaf see *Plant Biology*, Ch. VIII.

148. Forms of Leaves.—Before quitting the study of leaves we must observe a number of their general characters—their variety of form, arrangement of veins, etc. In order to do this we shall have to examine a considerable number, and to this end the student should take a country ramble, supplied with a book for notes and sketches, and a lens to assist his observations. We must necessarily be very brief in dealing with this part of our subject, and our instructions must be accepted as merely suggestive, and by no means exhaustive.

A typical leaf consists of a basal more or less sheathing portion, called the leaf-sheath or leaf-base, a stalk or petiole, and a flattened terminal portion, the blade or lamina. The leaf-sheath is usually simply the flattened basal portion of the petiole, but in most grasses it is of considerable size, and ensheathes the stem for some distance above the node from which it arises.

A sheathing **leaf-base** is frequently absent, but is especially well developed in such plants as Buttercups, Grasses, Dock, Umbellifers. The mode of insertion of different leaves exhibits a wide range of variation, but they always arise from the shoot or its branches. The so-called "radical" leaves simply arise from a very short stem (Prim-

rose, Dandelion). In some cases the base of the leaf is *decurrent*, and forms membranous outgrowths on the main axis, while it may even unite around the stem so as to form a *perfoliate* leaf.

Occasionally the leaf-base becomes thick and fleshy, and forms an irritable organ or organ of movement known as the *pulvinus*, which reacts to light in such a manner as to place the lamina under the best possible conditions of illumination. This is possible owing to the fact that the pulvinus retains the power of growth for some time after that of the rest of the leaf has ceased, as can easily be observed by watching Kidney Beans and altering the position of the stem from time to time.

In some plants the pulvinus responds quite rapidly to changes in the direction and intensity of the light. Thus the compound leaf of the Sensitive Plant (Fig. 32) places itself at right angles to the light falling upon it. Each leaflet, however, has a pulvinus of its own, and when the leaf is exposed to strong sunlight these pulvini curve in such a manner as to cause the leaflets to fold together in a few minutes, before they have time to be injuriously affected. At night, also, the leaflets fold together and go to sleep, as it were, while the whole leaf sinks downwards. In this position the leaf loses less water by evaporation, and remains warmer than it would be if expanded. The first movement is due to the action of strong light, the second to the absence of light, and their importance and utility to the plant are sufficiently obvious.

Very commonly wing-like outgrowths arise from the base of the petiole, and frequently these simply assume the form of lateral outgrowths of the leaf-base. The organs in question are known as **stipules**, although they cannot always be sharply defined. The stipules vary much in size, form, and colour. When they are quite small, dry, pale, and membranous they are usually functionless, but frequently they form large coloured protective bud-scales (Magnolia, Fig. Beech), and fall when the leaves unfold. In the False Acacia (*Robinia*) the stipules are metamorphosed into spines, and in *Smilax* they become tendrils. In some Peas they are large and green, and actually take the place and function of the foliage-leaves, which are modified into tendrils.

Stipules are often relatively large while the leaf is young, and in such cases they serve as a protection to the young buds or young foliage, frequently falling off as the leaf expands. When present upon adult leaves, the stipules aid in the production of organic food if they are green and they may also help to lead away rain water from the plant



Fig. 32.—Leaves of *Mimosa Pudica* (the Sensitive Plant).

a, Expanded day position ; b, Drooping folded night position.

so that it can dry rapidly, or to direct the water to those regions of the soil where the absorptive organs (root-hairs) are most abundant.

In the Rhubarb family (Polygonaceae) the two stipules join to form a tube (ochrea) enclosing the stem for a short distance above its junction with the leaf. The basal portion of a Grass leaf ensheathes the stem for some distance, and just between the stem and the base of the free portion of the leaf there is a small crescentic scale on the upper surface of the latter. This scale is termed the *ligule*.

149. Petiole.—Note that while some leaves have a distinct stalk (*petiole*), in others the lamina extends down to the stem of the plant. The latter are called *sessile leaves*.

The petiole is usually directly prolonged into the lamina as the midrib, but in the Garden Nasturtium (*Tropaeolum*) and in the Pennywort (*Cotyledon*) the stalk is attached to the middle of the under-surface (peltate leaf). A transition stage is shown by the leaves of the Water-Lily. The petiole may be winged, and it is usually cylindrical or semi-cylindrical, being frequently flat or even grooved on the upper surface.

The petiole is a special secondary structure developed in order to enable the lamina to expose itself to suitable illumination, and it is not always present. It contains strands of vascular tissue, which are continued into the lamina as the branching veins of the leaf. There is usually a large median vein, lying above a prominent midrib, although in other cases a number of veins of equal size enter the leaf from the petiole. In Garden Nasturtium (*Tropaeolum*) and Clematis, the petiole has the power of coiling around supports, and hence it acts as a tendril in spite of the presence of the lamina or blade.

150. Veins.—The veins are simply conducting bundles which run outwards from the stem into each leaf, and undergo considerable branching throughout the substance of the lamina. The larger veins usually project as ridges on the under-surface, but the smaller veinlets are buried in the tissue of the leaf. The arrangement of the smaller veinlets and the number of the larger veins differ in different leaves. This is what is termed the venation of the leaf.

Note that the leaves of all grasses, orchids, flags, wild hyacinths, and daffodils have all their principal veins running parallel through the entire length, and that these leaves are more or less elongated and blade-like. The leaves of most of our trees and herbs, however, have their principal veins branching off from the midrib on either side, while the smaller ones form a delicate network such as we observed in the bean leaf. The former arrangement (*parallel venation*) is characteristic of Monocotyledons, the latter (*reticulate venation*) of Dicotyledons (but also found in some Monocotyledons, e.g. Arum, Black Bryony).

If leaves are allowed to decay in water until the softer parts can be brushed away, skeletons of the harder parts can be obtained which directly exhibit the venation, but in most cases it is sufficient to hold up the leaf to the light to render the smaller veins plainly visible.

151. Simple and Compound Leaves.—Some leaves are *simple*; that is, their flat part or blade (*lamina*) is not divided into distinct portions, though they may be very deeply divided. Such is the case

with the leaves of the Oak, Hazel, Ivy, Dandelion, etc. These simple leaves exhibit a great variety of form, and the student should make a series of drawings illustrating the more typical shapes.

In compound leaves, of which we have already seen an example in the Bean, the blade is divided into distinct parts called leaflets, which may be arranged in opposite pairs along the central stalk as in the Rose and the Pea, or may all radiate from one point of the stalk as in the Horse-Chestnut.

The outline of the lamina assumes a great variety of forms, and special technical terms are given to the more strongly marked and more commonly occurring of these. It must, however, be remembered that all gradations exist between leaves of widely different shape, and since no general principles are involved in the application of these terms, they need not be discussed here. The following list includes the commonest shapes:—

(1) **Blade broadest near the base**—*e.g.* **cordate** (heart-shaped), **sagittate** (arrow-head-shaped), **reniform** (kidney-shaped), **ovate** (egg-shaped), **lanceolate** (lance-head-shaped, much longer than broad, tapering to pointed tip).

(2) **Blade broadest near the tip**—*e.g.* **obcordate**, **obovate**, **oblanceolate** (outline as in cordate, ovate, and lanceolate, but with the narrow end at the base), **spathulate** (spoon-shaped, *e.g.* Daisy).

(3) **Blade as broad in the middle as anywhere else**—*e.g.* long narrow forms, as **acicular** (needle-shaped), **linear** (long and narrow, with parallel margins), **cylindrical**; and rounded forms, as **orbicular** (circular), **elliptical**, **oval**, **peltate** (shield-like, blade nearly circular, but with stalk near the middle of lower surface).

Next observe the different kinds of **margins** of the blades. Some are even or *entire*, while others have sharp teeth which usually point towards the tip of the blade and resemble the teeth of a saw (*serrate* leaves), or have rounded teeth (*crenate* leaves). Note also the hairy (*ciliate*) margin of the Beech leaf, the wavy or *sinate* margin of the Oak, the irregularly toothed edge of the Dandelion, the spiny margin of the Holly, and various other modifications of leaf margins, all of which should be drawn from nature.

Very frequently the margin of the leaf is deeply indented, and if the indentations are regularly arranged, and are so deep as to reach the midrib, a compound leaf composed of a series of leaflets is produced. This will be *pinnate* or *palmate*, according to the arrangement of the main veins (Fig. 33), for the incisions will naturally fall between these.

Compare the simple leaves of the Ivy and the Beech, both of

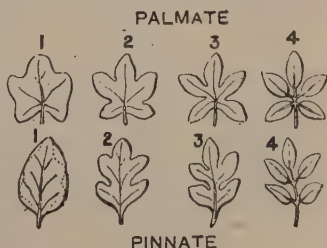


Fig. 33.—Formation of Palmate and Pinnate Compound Leaves by the gradually increasing incision of Laminas with Palmate and Pinnate Venation respectively.

which are of the net-veined type. Note that in the former the principal veins all radiate from one point at the base, while in the latter they branch off from the midrib almost throughout its length. Now since a compound leaf is produced by the division of the lamina between the principal veins, it is easy to see that the former, so divided, would produce a compound leaf with radiating leaflets. Such an arrangement of veins is termed *palmate venation*, and the leaves, both simple and compound, more or less divided in this fashion, are called *palmate leaves*. The arrangement of veins in the second instance is called *pinnate venation*, and by the incision of the lamina a *pinnate leaf* is produced, which, in the case of the compound leaf, would have opposite leaflets.

A compound leaf is easily distinguished, even by beginners, from a branch bearing leaves because of the absence of any apical bud or growing point, and by the fact that a bud occurs in the axil of the main petiole, whereas there are no buds in the axils of the leaflets.

152. Leaf-Arrangement.—Observations should also be made of the different ways in which the leaves are arranged on the stem. There are two ways in which leaves are arranged—*alternate* (one leaf arising at each “node,” i.e. the leaves coming off *singly* from the stem) and *whorled* (two leaves, rarely more, arising at each node).

The simplest type of alternate arrangement is that seen in the Broad Bean and in Grasses, where the leaves come off alternately from opposite sides of the stem, so as to form two rows; this is called the $\frac{1}{2}$ arrangement, because each leaf is separated from the next above and below it by one-half the circumference of the stem. The next arrangement ($\frac{1}{3}$) is seen in young shoots of Hazel, where the leaves are in *three* rows. Alternate leaves obviously form a *spiral*, the nature of which may be easily determined by tying a piece of cotton to the base of a leaf, and carrying it in order to the bases of the leaves above, twisting it around each one. Suppose, for instance, we do this in the case of a young shoot of the Hazel; we find that each leaf is one-third round the stem as compared with the one below it, and consequently the fourth leaf is vertically above the first, being the starting-leaf of a second turn of the spiral.

One of the commonest spiral or alternate arrangements is the $\frac{2}{5}$, seen in Wallflower, Oak, and many other plants; here the sixth leaf is above the first and the spiral goes twice round the stem in passing from the first leaf to the sixth. Another fairly common spiral is the $\frac{3}{8}$, seen in Daisy, Plantains, etc. Do you notice how these commoner spiral arrangements are related to each other?

When leaves are arranged in pairs, the two leaves being on opposite sides of the “node,” each pair is usually set at right angles to the pair above and the pair below. That is, the leaves are in four rows, the pairs being crossed. This *decussate* arrangement is very common, e.g. Nettles, Labiates, Sunflower, Sycamore, Ash, Lilac, Horse-Chestnut, Campions, Stitchworts, Chickweeds. Comparatively few plants have three or more leaves in a whorl or circle at each “node”; this is seen in Mare’s-tail (*Hippuris*) and in Heaths. The leaves are *apparently* in whorls in Goosegrass and Bedstraws (Art. 279).

153. Leaf-Mosaics.—Instead of giving further details here about the various modes of arrangement of leaves on the stem, we will call attention to the *reasons* why leaves have such varied arrangements and shapes. It is not always easy to explain the different forms of leaves in different plants, but some general principles can be inferred by remembering the *functions* carried on by leaves while studying their form and structure. The main fact to remember is that leaves require to catch as much sunlight as possible, especially in a country like ours, where the number of hours of sunshine is rather scanty. The south coast of England only gets about 1,600 hours of sunshine annually, and in the rest of Britain the number is usually far below this.

A leaf which receives very little light or no light at all during its development grows feebly, and cannot, of course, carry on carbon-assimilation. Moreover, when a leaf is shaded by another leaf being placed between it and the light, very little assimilation occurs. Hence we find that in many plants the leaves tend to fit together like the bits of glass in a mosaic or the tiles in a pavement, so as to avoid shading each other and to lose as little sunlight as possible. This tendency is easily seen in (1) plants whose leaves are crowded together and form a rosette close to the ground—*e.g.* Daisy, Hawkweed, Plantain, London Pride; (2) many plants with whorled leaves—*e.g.* Woodruff; (3) twigs of many trees—*e.g.* Horse Chestnut, Beech, Elm, Lime; (4) twigs of plants which creep along a wall or bank—*e.g.* Ivy. In Labiates (*e.g.* Dead-Nettle) and Stinging-Nettles the lower leaves have broader blades and longer stalks than the upper ones.

Even when the "mosaic" tendency is not at first glance apparent, careful study of the plant *in its habitat*, or home, will often show adaptations for efficient light-catching. It must, of course, be remembered that the strongest light does not, in this country, come from directly above, but at an angle, even when plants are growing on level ground. In studying the plants dealt with in the later chapters of this book, you should notice and try to account for the position, stalk-length, shape of blade, and other arrangements of the leaves, remembering that, besides the tendency to catch as much light as possible, the forms of leaves are often influenced by other causes—*e.g.* the necessity to withstand high winds,

to carry away rain which falls on the blade, to catch the light when growing in dense masses (*e.g.* grasses and plants growing among them in fields).

This interesting subject can only be studied by personal observation; any field, wood, hedgerow, or garden will afford abundant material to illustrate the points here mentioned, and to show how the arrangement and shapes of leaves help plants in the struggle for light and air, which is, of course, keenest where plants are growing in crowded fields or hedgerows.

154. How Leaves are Protected.—We shall see later that young leaves nearly always have some mode of protection against loss of water; they are often covered with hairs, which may disappear as the leaf grows to its full size, or they may be bathed in a gummy or resinous liquid; or they may be rolled or folded up at first. These protective arrangements are especially necessary when the leaf is young and its tissues tender and liable to lose water readily, or to be injured by strong light or by cold.

In many plants the mature leaves show similar protective arrangements, which are especially marked in plants which grow in places where they are exposed to strong light, to drying winds, cold, and other injurious conditions, such as a scanty or precarious supply of water. Most evergreen plants have a thick cuticle, or a layer of clear cells below the upper epidermis, and the stomates are often sunk below the level of the epidermis. Other arrangements by which transpiration is diminished is the rolling up of the leaf (Heather, etc.), or a thick covering of hairs (Woolly Mullein, etc.), especially on the lower surface of the leaf (Coltsfoot, etc.), to which the stomates are restricted in most firm, thick, or leathery leaves.

It is easy to show that a dense covering of hairs checks the rate of transpiration, by using the apparatus shown in Fig. 29 A (Art. 142) after fastening to each leaf a piece of cotton-wool so as to cover the lower surface of the leaf, or both surfaces, and noting the effect this has on the rate at which the leaves give off water-vapour. The effect of rolling can be observed by folding the leaf or rolling it up longitudinally to form a tube with the lower epidermis on the inside and tying it with thread, and noting the reduced rate of transpiration.

Many leaves also have their surface covered with waxy matter or "bloom," so that they are not wetted by rain. This is well shown by the Broad Bean, *Tropaeolum*, Cabbage, and many other plants. The "bloom" not only prevents water from entering the leaf and blocking up the air-spaces, but also helps in reducing transpiration; if the "bloom" is removed from an Indianrubber Plant leaf by sponging its surface with warm water, the leaf will lose more water than one with the bloom untouched.

155. Decay and Fall of the Leaf.—Leaves which fall before the vegetative season is over are *caducous*; *deciduous*, if they fall at the end of each season, as in most cases of our forest trees; *persistent*, if they remain on the plant for more than one season, as in evergreens. The leaves of such plants as Grasses, Lilies, Irises, etc., simply wither on the stem, but in most trees the fall of the leaf at the end of the vegetative season is brought about by the plant itself. When the activity of such leaves is nearly over, and they have been partly emptied of the food-substances they contain, a layer of cork-tissue forms across the base of the leaf, and by interposing an impermeable layer between the leaf and the stem, cuts off from the former all supplies of water and mineral salts.

The exact structure and development of this **absciss-layer** cannot be fully gone into here, but what occurs in the actual "fall" of the leaf is the splitting of this layer in such a way that the leaf only hangs on by the veins which pass from it into the stem, and then these snap, leaving the scar of attachment of the leaf already healed and covered with cork. The process is a vital one due to the activity of the living plant, for if a branch is killed by means of hot water the leaves wither upon it without being shed. On the other hand, leaves can be made to "fall" in summer by wrapping them in a damp cloth.

Whenever the plant requires to throw off certain organs at a definite time (petals and other floral parts after fertilisation; fruits and seeds when ripened) it generally makes use of similar absciss-layers.

QUESTIONS ON CHAPTER III.

1. What differences exist between the cotyledons and the foliage-leaves of the Broad Bean? How may these differences be accounted for?

2. How could you prove that a leaf has air-spaces inside it and air-pores on its surface?

3. Describe the structure of a typical foliage-leaf.

4. How could you prove that a green leaf makes food when exposed to light?

5. Under what conditions is starch formed in the foliage-leaves of an ordinary land plant? Give experiments in proof of each statement.

6. What is a stomate, and how does it work? Why do people often syringe or sponge the leaves of plants grown indoors or beside a dusty road?

7. To what substance do the green parts of plants owe their colour? State and explain the nature of the work which only the green parts of plants are able to perform.

8. Explain how it is that a green plant cannot carry on its nutrition in darkness.

9. What constituent of plant-food is obtained from the atmosphere? What changes do plants affect in it? Describe an experiment to demonstrate this.

10. What is meant by the term Photosynthesis? What is the first *visible* result of this process, and how would you detect it in a leaf?

11. What gases would you expect to find in the air of a closed glass vessel exposed to light before and after leaving a green plant within it? State the relative quantity of the various gases, and how the presence of each can be detected. How could you measure the quantity of each gas?

12. Two leaves, while still attached to the plant, are kept in the dark for twenty-four hours; then one is exposed to sunlight for some hours, while the other still remains in the dark. By what after-treatment would you distinguish between the two? Explain your exact procedure and the reasoning on which you base your conclusions.

13. Explain as fully as you can how it is that the guard-cells of a stoma are enabled to alter the size of the aperture between them.

14. What is the importance of carbon to a plant? From what source does a green plant get its carbon, and how is it assimilated?

15. What do you consider the essential characters of the foliage leaves of a green plant -*i.e.* the characters in which all or nearly all leaves you know agree? How are these features of leaves of service to the plant?

16. What are the "veins" of a leaf? What are their uses? How would you show, by experiment, the correctness of your statements?

17. Describe the continuous Spectrum. How is the appearance of the spectrum affected by an extract of chlorophyll being placed between the prism and the screen on which the spectrum is received?

18. What is the function of Chlorophyll? Under what conditions is it formed, and how does it occur in the plant?

19. Give an account of the process of transpiration. By what means does the plant regulate its transpiration?

20. If on a warm sunny day a plant growing in a pot had become limp and "wilted," how could you restore it to its normal condition without watering it in any way?

21. Why does the inside of a Cabbage consist of lighter coloured, thicker, and more succulent leaves than the outside?

22. Explain why it is that plants droop on a hot day, and recover their freshness in the evening.

23. Describe experiments you have made on Transpiration, and explain how the rate of transpiration is affected under different conditions.

24. Mention the different forms which may be assumed by the stipules of plants. Give one example of each, and state the special use of the stipules in each case.

25. Explain how you would proceed to make a water culture. Indicate the effect, on the plant, of the omission of salts containing calcium, potassium, and nitrogen respectively.

26. How could you prove that nitrates (of soda, potash, or lime) are present in a fertile soil?

CHAPTER IV.

THE GROWTH OF ROOT AND SHOOT.

156. We have studied the leaf and its chief functions first, because the work of the leaf is of the highest importance. As we have seen, the green leaf manufactures organic food from the raw materials which it takes from the air and from the soil, and it also serves as the chief means by which the air within the plant communicates with the atmosphere, and by which the gaseous exchanges concerned in respiration and transpiration are carried on. These functions are also carried on by the other green parts of plants, *e.g.* by young stems, both in herbaceous and woody plants, since the rind (cortex) contains chloroplasts, and the stomates (on herbaceous stems and the youngest parts of woody stems) or lenticels (in older parts of woody stems) communicate between the air-spaces in the plant and the atmosphere outside. In some plants, even the roots, or some of them, act as assimilating organs, as in the aerial roots of various tropical Orchids and Aroids.

We have already learned something about the growth of roots and shoots from our work on seedlings and on the nutrition of the green plant. We may now take up the questions on the growth of root and shoot raised at the beginning of the previous chapter (Arts. 107-109), and proceed to the study of root and shoot in a more detailed manner. It is absolutely necessary to grasp thoroughly the main facts in the nutrition of plants—above all, the **work of the green leaf**, which is the great fundamental process and which may be said to form the key to the right understanding of the structure and development of root and shoot and all the varied forms and adaptations of the vegetative organs, besides having a direct influence on the processes of reproduction.

157. How to measure the Growth in Length of Root and Stem.—Seedlings of Broad Bean, Garden Pea, and Scarlet Runner are suitable for experiments on the growth in length of root and stem. Place the seeds in damp sawdust with the scar downwards. Sow some French and Runner Beans in pots; they are especially useful for measurements of the growth of the stem. When the root has grown about 2 inches long, dry its surface carefully, stroking it with torn bits of blotting-paper, and with a fine brush mark it at intervals of $\frac{1}{8}$ inch, starting at the tip, with dots or transverse lines of Indian ink; then dip the root in water before proceeding with the experiment. The stem of a French or Runner Bean seedling should be marked in the same way, starting at the point where the first pair of foliage-leaves stand on the stem and working downwards; seedlings of Sunflower or Mustard may be used, the hypocotyl being marked starting from the cotyledons.

158. Where does Growth in Length occur?—Pin a seedling with marked root to the cork of a glass jar, exactly as in Fig. 11. Examine from time to time and note the positions of the marks; after a few days, the marks just behind the tip of the root will be widely separated, while those farther back have changed little, or not at all, in position. What conclusion can you draw from the results of experiments like this? To what region of the root is growth in length almost entirely restricted?

A neat method of arranging this experiment is to put the seedling into a thistle-funnel and let the root grow down the tube; the latter is set in a jar of water, while the seed is covered with some wet blotting-paper or cotton-wool. This plan, allowing the roots to grow very long, gives striking proof of the fact that growth in length chiefly occurs just behind the root-tip. An ordinary glass funnel may be used instead of a thistle-funnel.

Daily observations and measurements of the hypocotyl of a French Bean seedling, or the young shoot of a Runner seedling, will show that in the stem, as in the root, growth in length is much more vigorous just below the tip than farther down.

159. How the Young Root enters the Soil.—You have seen that the root end of the axis is the first part of the young plant to emerge from the seed, and that on emerging it grows downwards, in whatever position the seed has been placed. Have you tried the effect of moving the seed at this stage, and then turning it over each time the root has curved so as to be directed downwards? Have you noticed how, if a seed is laid on firm soil, root-hairs grow out and fix the root to the soil, giving it a “purchase,” so that it can push its tip down with greater force? Have you noticed how the lighter kinds of seeds are often raised up or turned right over by the struggles of the root to bore into the soil?

160. With what Force can the Root push downwards?—You have seen that the young shoot can exert great force in its upward growth (Art. 87). How can the downward pushing power of the root be measured, say in a Broad Bean seedling? Here are (a) a method of demonstrating the downward force exerted by the root, (b) and (c) two simple methods by which this force can be roughly measured.

(a) You have probably used mercury in various experiments, and know that it is a very heavy liquid ($13\frac{1}{2}$ times heavier than water). Fix a seedling (Bean, Pea, etc., should be tried) to the side of a small dish containing mercury with a layer of water above it, and see whether the root will grow down into the mercury. The seeds may be pinned to a cork which is securely fixed to the rim of the dish (*e.g.* a saucer) by making a slit in it and jamming it tightly on the rim; each seed should of course be fixed by *two* pins.

(b) One method of roughly measuring the pushing power of the root is to make it press a cork, or a chain of corks, downwards into water. Cut a slit in a cork so that it can be firmly fixed to the rim of a tall, narrow jar or a large test-tube, and to this cork pin a Bean seedling (with a root about 2 ins. long) so that its root projects into the mouth of the tube. Then place in the tube a number of corks, one above another, of such size that they can move freely inside the tube; the row of corks should be about half as long as the tube. In the uppermost cork make a cavity for the root to press downwards against, and pour some water into the tube so that the root fits into this cavity. Place a vertical strip of paper on the tube, on which to mark the position of the lowest cork from day to day, and put some wet cotton-wool or blotting-paper over the seedling to keep it moist.

Each day pour a little more water into the tube (which should be fixed in the vertical position), and thus increase the resistance against

which the root has to push downwards. When the root seems unable to push the chain of corks any farther down, mark the position of the bottom of the lowest cork, then take the seedling out and find what weight (e.g. of shot in a test-tube) is required to depress the corks to the same mark. By finding the diameter, and from this the area, of the root just above the tip, you can calculate the pressure of the down-growing root in grammes or ounces per square centimetre or square inch.

(c) Fix a young Bean-seedling so that its root grows in a small tube filled with moist soil or sawdust, and place this tube within a larger one containing a spring. The root grows downwards with a force equal to over 300 grammes (about 11 oz.); measure the diameter of the Bean-root and calculate the force it exerts per square centimetre or square inch.

161. What makes the Main Root grow downwards and the Main Stem upwards?—Most likely this question would not have occurred to you at all, or if it had you would probably have thought of anything but the right answer or the right way to test the matter. It is clear that the root *does not simply bend down by its own weight*, like a rod of plastic material, for it exerts great force in its downward growth. Besides, this “explanation” would not apply to the shoot, nor even to the side-roots; the former grows upwards, the latter grow away from the parent-root.

If the young root is placed horizontally, it soon begins to bend downwards, the curvature taking place just behind the growing apex. This curvature is soon rendered permanent by the growth and hardening of the tissues affected, but a new terminal straight portion of the root is soon formed as growth continues, and if this be again laid horizontally a downward curvature is produced as before. This curvature is due to the fact that **gravity**, the attractive force which the earth exerts on all bodies, acts as a stimulus upon the protoplasm at the apex of the root, and causes the growing region to bend towards the centre of the earth.

That it is not the action of the *soil* which causes the root to grow downwards is readily shown, e.g. by growing seedlings in moist air.

(a) Choose a few Bean seedlings with straight roots about $1\frac{1}{2}$ in. long. Dry the roots gently by stroking with pieces of blotting-paper, and mark each radicle at intervals of $\frac{1}{8}$ in. by making transverse lines with Indian ink, beginning at the tip. Pin the seedlings to a piece of wood or a cork, and invert it over a wide-mouthed jar containing a little

water. Fix different seedlings with the radicle pointing upwards, downwards, and horizontally. From day to day observe and sketch the appearance of the seedlings, noting the direction of growth of the shoot and the root.

(b) Grow Bean or Pea seedlings in your box with a sloping glass front. When the side-roots have grown out, mark on the glass the positions of a few of these, also of the main root; note especially the position of the *tip* of each root. Then tilt the box up at an angle of about 45° , and notice how main root and side roots change their direction of growth.

162. How does Moisture affect the Direction of Growth?—Is the main root bound to grow vertically downwards in *all* circumstances, or could it be induced to change its course by some other stimulus? We know that roots require moisture. Would the main root leave its vertically downward course in order to grow towards a moister part of the soil? Would this be a useful thing for the root?

(a) Lay a glass jar on its side (a jar with flat sides is best) and put a sponge, soaked with water, in the closed end. Fit the jar with a cork (bored with a hole for ventilation), and to the inner side of the cork fix a Pea or Bean seedling by putting two pins through the cotyledons. Fix the cork so that the root lies horizontally. Does the root bend and grow towards the wet sponge, the shoot towards the mouth of the jar?

(b) Grow seeds in a box with a bottom of wire gauze, and hang the box up or tilt it by putting a wood block under one end. The roots grow down through the gauze into the dry air, but they soon curve and grow upwards again. Why?

(c) Take a tumbler or jar about a quarter filled with water, tie over it some muslin, and on it place some damp sawdust with several soaked seeds, then invert a larger tumbler over the whole. The roots on emerging from the sawdust do not turn back, but grow down in the damp air. Compare with (b).

(d) In the middle of a box of dry soil or sawdust place a flower-pot, first plugging the hole in it by a cork. Place some soaked seeds in the sawdust around the flower-pot, but do not water except by pouring water into the flower-pot, and filling the latter up as the water evaporates. After a few days, gently pull up a seedling and see whether its root has curved towards the pot.

163. How does Light affect the Direction of Growth?—Have you noticed the appearance of plants growing near a window?

(a) Set some seedlings in such a position that the light falls on them mainly from one side, and notice the effect this has on their shoots. After marked bending has been observed, turn the seedlings round and see whether the shoots again respond to the "attraction" of light.

(b) Take the wide-mouthed glass jar and cover it outside with black paper or cloth, leaving a narrow vertical chink on one side. Fix a Bean seedling horizontally inside the jar, at right angles with the chink. Does the root bend, and does it bend towards or away from the light? In what direction does the shoot bend?

(c) Pass the roots of germinated Cress, Radish, or Linseed through holes in muslin tied over a tumbler filled with water. Set the tumbler close to a window, or in a box with a vertical slit in the side turned to the light, or use a black sheet, as in the preceding experiment. Observe the direction in which root and shoot grow with regard to the light.

It is interesting to note that plants grown in red light often show one of the effects of darkness—their stems are usually long; but the leaves are well developed and turn green. In blue light plants develop small leaves and show very marked bending towards the source of light (heliotropic curvature), but they soon die.

164. How does Contact affect the Direction of Growth?—As we shall see later, some parts of plants are very sensitive to contact, *e.g.* tendrils. Has the root this kind of sensitiveness? How does the growing young root behave when it comes against an obstacle which it cannot push out of its way? The root can force itself through loose soil even when young and soft, and when it grows old and hard, becoming thicker year by year, it can exert enormous pressure against anything around it. Have you ever noticed the raising-up and splitting of asphalt-pavements around the roots of trees in towns? Have you ever seen the cobblestones of a courtyard pushed up by the growth of a mushroom-like fungus? If so, you will have some idea of the force which growing plants are able to exert.

(a) To the inner side of the glass in your box with glass front fix with sealing-wax small pieces of wood, some with holes bored in them, and plant seeds a little above these obstacles. Notice that the roots diverge from their course only so much as is absolutely necessary to avoid the obstacles, and resume their original course as soon as they have passed one.

(b) Another method is to use a glass funnel filled with moist soil or sawdust; plant the seeds close to the glass near the top of the funnel, and fix the obstacles an inch or more below them.

(c) With the point of a knife remove a small portion of the yolk of a hard-boiled egg, and apply it to one side of the tip of the radicle of a Bean-seedling (choose one with a straight root about 2 ins. long); fix

the seedling vertically in a jar containing some water at the bottom, and keep in darkness. After a few hours, see whether any curvature has taken place, and, if so, in what direction. The one-sided irritation, due to the presence of the foreign substance, has exerted a stronger influence than that of gravity, and has caused the bending of the root.

165. Test-Tube Experiments.—For demonstration to a class, some of the foregoing experiments may be conveniently duplicated by arranging them on a small scale in test-tubes, which are handed round the class. The following will serve as examples:—

(a) Get a test-tube with a cork to fit, pin to the cork a Pea-seedling with a straight root 2 ins. long, put a strip of blotting-paper in the tube, and run in water to soak it. Fix the seedling in the tube with its root pointing to the closed end, and keep the tube in a vertical position, with the corked end uppermost.

(b) Fix a similar seedling in a tube, but keep the tube inverted, so that the root points vertically upwards.

(c) Get a similar seedling and tube, but with a razor or sharp knife cut off the extreme tip of the root, and keep the tube in the same position as in (b).

166. The Root-Tip a Sensitive Organ.—From the foregoing experiments it is clear that the root responds, by changing its direction of growth, to the influences or stimuli of moisture, light, and contact. We have also seen that the main roots always grow vertically downwards, towards the centre of the earth, except when deflected from this direction by one of the stimuli just mentioned. It will be noticed that the shoot of a seedling grows towards light and away from moisture, its responses to these stimuli being the opposite of those made by the main root. The force of gravity also has a stimulating effect on the growth of root and shoot, and the response made is such that the root tends to grow down in the direction of the force, the stem to grow up in the opposite direction.

That these opposite tendencies of root and stem are to be ascribed to gravity has been determined by experiment. There is a machine called the **clinostat** (Art. 167), consisting essentially of a plate mounted on a horizontal axis, and therefore rotating vertically. A plant is attached *horizontally* to the plate, and the axis is rotated *slowly*. A little reflection

will show that the normal influence of gravity is eliminated, as each side of the axis is, in turn, directed downwards. Stem and root simply continue to grow in whatever direction they are placed.

Another experiment is to attach a plant to a wheel which rotates *rapidly* and *vertically*. Here another force—"centrifugal force"—somewhat similar to gravity, comes into play. If the opposite tendencies of root and stem are to be ascribed to gravity, we should expect similar tendencies to be exhibited under the action of "centrifugal" force. This is the case; in seedlings fixed to the vertically revolving wheel, the roots bend away from the centre of the wheel and grow straight out in the direction of the radius, while the stems grow straight in towards the centre of the wheel.

What will happen if the wheel revolves *horizontally*? Two forces now act on the plant, the centrifugal force and that of gravity, and the root bends obliquely outwards, the stem obliquely inwards.

Side-roots are but little sensitive to gravity; they grow out from the parent root, each growing in a definite direction. If the growth of a side-root is towards, say, the east, and it is interrupted by a stone, as soon as the root has reached the edge of the stone it will resume its eastward direction of growth. The branches of the side-roots, again, grow away from these, and may therefore grow in a downward, horizontal, or even upward direction. In the last-mentioned case, therefore, we get some branch-roots actually growing in a direction opposite to that of the main root—that is, making an exactly opposite response to the stimulus of gravity.

We have also found by experiments that the attraction-stimulus of gravity may, even in the case of a main root, be overcome by the attraction-stimulus of moisture or by the repulsion-stimulus of light, while contact with an obstacle like a stone causes the root to change its direction of growth for a time, though it resumes this direction as soon as it reaches the edge of the obstacle. It is clear, therefore, that the root is a sensitive organ, its sensitiveness or "irritability" being much the same as that of an animal.

It is very important to understand that geotropism and other forms of irritability in plants answer to the various kinds of sensation in animals, and also to try to see the *reason*

for each response made by each part of a plant to each kind of stimulus from outside it. If you have carried out the preceding experiments, stop here and think out for yourself *why*—i.e. to what advantage—the main root of a bean or pea (or other plant you have worked with) grows downwards, *why* it grows towards moisture, *why* it grows away from light, *why* a root turns off on meeting an obstacle and goes on its former course after getting to the obstacle's edge, *why* a branch-root grows away from its parent-root. In each case remember the two great functions of the root (what are these?) and the need for the root-system to explore the soil thoroughly and to come into contact with as much soil as possible, in order to do its work efficiently.

The fact that the removal of the root-tip destroys the power of the root to respond to the stimuli of gravity, etc., goes far to prove that this is the sensitive region of the root, but such experiments are not conclusive, because curvatures due to the injury usually take place; the root sometimes forms a new tip, and then responds to stimuli as before.

The fact that the root-tip alone is sensitive to the stimulus of gravity has been shown by the following method:—Seedlings of Broad Beans are rotated on a clinostat (see Art. 167) and their roots caused to grow into small L-shaped glass tubes, open at one end, so that the root is sharply bent at about $\frac{1}{16}$ in. from its tip. They are then placed in various positions, each having this small glass boot on its root. If the tip is vertical, and the basal part of the root horizontal (Γ), *no curvature takes place*, though the radicle grows vigorously in the horizontal direction. If the tip is horizontal (L), the vertical part of the root outside of the tube bends until the tip of the root is vertical.

167. The Clinostat.—The principle of this apparatus is very simple. Nothing on the earth can be removed from the influence of gravitation, but it is possible to make gravitation neutralise its own effects. A simple form of clinostat, to carry seedlings, is easily made. Here is a method of making one which answers fairly well. Get a cheap but strongly made eight-day clock, and fasten to the axle of the minute-hand a disc of wood about 2 ins. in diameter, so that the disc will revolve parallel to the face of the clock. Get a thin, shallow, glass dish (crystallising dish) about 6 ins. in diameter, with a cork to fit it, and fasten the cork to the disc with pins. On the cork pin several seeds in different positions, put wet bog-moss between them, and fix on

the dish. Get a similar dish and cork, and pin to the latter the same number of seeds (Beans or Peas) in the same positions, and fix it upright as a control. The roots of the seedlings on the fixed cork will all bend downwards; those on the revolving cork will grow straight out from the seed, and will therefore be directed at various angles.

168. Regions of the Root.—From your observations on the growth of roots, it will be evident that the increase in length of a root is almost entirely due to the elongation of the region lying a short distance behind the root-tip, also that root-hairs only arise where the root has ceased to lengthen, and that branches only arise still farther back (*why* do not root-hairs and branches arise where the root is still growing in length?). The following regions may be distinguished in a root:—(1) Growing-point, covered by root-cap; (2) elongating or growing region; (3) region bearing root-hairs; (4) thickening region, which may bear branches (rootlets).

169. How is the Root-Tip protected against injury as the root pushes its way into the soil?

A little behind the actual tip of the root lies the growing-point, which is covered and protected by the root-cap. The growing-point consists of cells which are constantly dividing, growing after each division, then dividing again, so as to produce new cells. Most of these cells go to form the main mass of the root, but those formed towards the tip of the root add to the root-cap. The root-cap is, therefore, continually renewed from within as it wears away outside; compare with this the way in which one's skin is renewed. The onward growth of the root is due to the formation of new cells at the growing-point and to their elongation (and further division) behind the growing-point. The growing-point is not only the factory where new cells are made; it is also the sensitive part of the root, which alone can perceive the stimuli of gravitation, etc., and by sending them on to the region behind cause the bending movements we have studied.

Examine with the microscope the roots of any small seedlings (Cress, Mustard, Wheat) mounted in water on a slide. Focus on the upper surface, and notice the outer layer of cells (skin-layer or epidermis) immediately behind the extreme tip. Sketch part of this, then focus

deeper so as to get an "optical section" of the growing-point, and try to make out the tissues as shown in Fig. 34, the root-cap covering the denser layers of cells which form the growing-point, and which gradually pass backwards into the central cylinder, the rind (cortex),

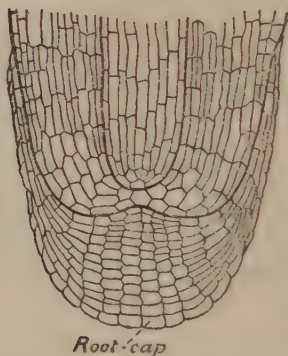


Fig. 34.—The Root-Tip, in Section, magnified.

and the epidermis. Trace the origin of root-hairs, each of which is a long slender tube, closed at the free end; each hair arises as an out-growth from a single cell of the skin-layer. Farther behind the root-tip the root-hairs are longer, but they are absent from the oldest parts of the root—*i.e.* those nearest the stem. Crush a root by pressing it under the cover-glass, and observe the vessels in the central cylinder; some vessels have a spiral fibre coiled inside them, others show small spots (pits), which are thin places in the wall. Notice also the large cells of the rind (cortex). Try to find the beginnings of side-roots and different stages in their growth (see Fig. 2).

170. The Conducting Channels of the Stem.—From your study of the functions of the leaf, you should be able to draw some conclusions regarding those of the stem. Some further experiments will give additional information about the part played by the stem in the process of transpiration.

(a) Place whole plants, or seedlings, or cut twigs, into water coloured with red ink, set them where the conditions are favourable for transpiration, and after an hour or so cut across the stem a few inches above the level of the coloured water. If the latter has risen in the stem, trace it upwards by means of successive cuts, then replace the plant in the liquid, and after a time notice its appearance in the leaves, as shown by the colouring of the veins.

(b) Make thin cross-sections and longitudinal sections of these plants. In most cases notice that the bundles are arranged in a single ring; this arrangement is found in most Dicotyledons. In Grasses, Lilies, and other Monocotyledons, the red-stained bundles will be seen to be scattered through the stem. Notice that in most cases only the inner part of each bundle is stained. In Vegetable Marrow or Cucumber the bundles are in a double ring, and here the central part of each bundle is stained.

(c) Place a twig of a tree—*e.g.* Oak, Beech, Elm, or any other hard woody plant—in the coloured water, and when the leaf-veins become coloured, cut across the stem, starting in this case at the top where the stem is soft and green. At the top notice that the bundles are separate; but as we pass downwards, making successive cuts, the bundles appear to fuse and form a continuous ring.

(d) Cut two twigs of a woody plant—*e.g.* Willow—about equal as regards length and the number of leaves. Cut round one of the twigs, a few inches from the lower end, as far in as the hard woody part, and remove from the lower part of the stem the whole of the soft outer tissue. Leave the other twig uninjured, and set both twigs into red ink. Notice that the removal of the outer tissue makes little or no difference as regards the rise of the red ink in the stem and its appearance in the veins of the leaves.

(e) Take a Bean seedling which has been pulled up and allowed to lie for some time, till the leaves have begun to wither. Place the seedling with its stem under water coloured with red ink, then cut across the stem under the coloured water. Take the stem out and notice that the water has run up, in the bundles, for some distance. This shows that when the leaves are transpiring and the roots are not absorbing enough water, there is a “negative pressure” in the water-carrying channels, so that when the stem is cut under the coloured water, the liquid rushes in.

The foregoing experiments show (1) that one function of the stem is to carry water from the roots to the upper parts of the plant, and (2) that the water travels through the inner portion of each bundle when the bundles are separate and through the hard woody part of a stem when the bundles are joined to form a continuous cylinder. Through what channels do the organic substances produced in the leaves travel to other parts of the plant? If these also travel along the bundles, they must pass through the soft outer tissue in the case of a woody stem; and in that of a stem, with separate bundles, these substances must pass either through the part of each bundle which was not stained by the red ink or else through the other tissue of the stem, or by both routes. Before considering this question, we must know more about the structure of the stem; but the following

experiments will give a clue as to the paths by which leaf-manufactured food travels.

(f) Place a Bean seedling or a Garden Nasturtium (try various other plants) in darkness for a few days, then remove some leaves and test them for sugar by boiling them in Fehling's solution. There will be little or no red coloration, showing that sugar is absent, or nearly so. Expose the plant to sunlight for several hours, then place it in darkness (after having tested some leaves, or parts of leaves, for starch), and after a time test some leaves for sugar, which will be indicated by the red colour produced around the veins. If the presence of sugar is detected in this way in the leaf-blade, test sections of the leaf-stalk at different levels, to find out by what paths the sugar travels towards the stem. Also test sections of the stem itself. By careful use of Fehling's test, it is easy to prove that the sugar travels in the leaf itself along the tissue surrounding the veins (bundles), and in the stem it is to be found in the ground tissue in which the bundles are embedded.

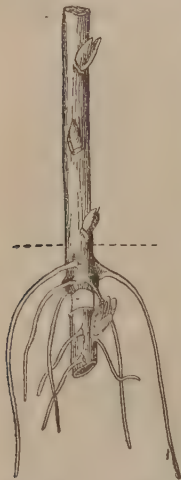


Fig. 35. — A Ringed Branch of a Willow sprouting in Water.

(g) Make two cuts round the lower part of a Willow twig, about an inch apart, and remove the soft outer tissue of the stem between these cuts, so as to leave only the hard woody portion of the stem for this distance. Then set the twig in water (which should be changed every day) or in culture-solution, and notice that it begins to sprout after a few days (Fig. 35). Below the injury the development of buds and new roots takes place but slowly, whereas above it new roots are rapidly formed and nourished by food conveyed from the upper parts of the branch by the tissue lying on the outer side of the wood. This experiment usually succeeds best in spring or early summer. Later in the year it is advisable to remove the leaves in order to diminish the loss of water, since there are no roots on the cutting to keep up the supply of water. The rapid development of buds and the formation of roots above the ringed part show that food passes down chiefly through the soft outer region of the stem.

171. Chief Functions of the Stem.—The leaves must be exposed to air and light in order to carry on their work of food-making, and in this work they require supplies of water containing dissolved salts. The food made by the leaves has to be carried to other parts of the plant which are living and

growing or acting as storage-organs. The roots, having no chlorophyll and not being exposed to light, cannot, of course, carry on photosynthesis, and must therefore be supplied with organic food made in the leaves.

From these considerations, and from the results of our simple experiments, it is clear that the ordinary functions of a stem are (1) to bear the leaves and help in spreading them out to light and air; (2) to convey water with dissolved salts from the roots to leaves and other parts of the shoot; (3) to carry organic food from the leaves to other parts. These are the primary functions of the ordinary stem, but in addition to this stems often have to take on special functions. Thus they may serve as organs of vegetative propagation, as store-places of nourishment, etc.

Stem-structures assume an immense variety of forms, according to their special adaptations. Some (*e.g.* Broad Bean, Foxglove, Sunflower, Lily) grow straight up, and are self-supporting; this is the typical form of stem. Others are *weak stems*, incapable of themselves of growing erect, *e.g.* stems of submerged water-plants, runners, climbers. Most stems are aerial, but many are buried in the soil, and are called underground stems. Some are soft (herbaceous); others are hard and woody. Most woody plants form shrubs or trees, and are *perennial*—*i.e.* persist for a number of years. Herbaceous plants may be *annuals*, living only during one season and dying down in the autumn; others are *biennial* (*e.g.* the Turnip), living during two seasons. In the first year they produce only vegetative shoots; in the second, flowers, fruits, and seeds. Many herbaceous plants, however, which die down in the autumn perennate by means of their underground stems. Shrubs and trees are often termed *arborescent* or *arborescent* plants.

172. Structure of the Stem.—In Dicotyledons, both in herbaceous stems and in woody stems when young, isolated bundles run through the stem, forming a hollow cylinder (a ring, as seen in cross section). In Monocotyledons the bundles are scattered through the ground-tissue of the stem. This is because in the former case the bundles (veins) which run into the stem from the leaves remain near the surface, ultimately joining bundles from other leaves and

increasing in size, whereas in Monocotyledons the bundles from each leaf run deep into the stem and curve outwards lower down, tapering away as they do so. Hence the bundles on the outside of a transverse section are in this case smaller than the central ones, whereas in the Dicotyledon the smaller bundles alternate with the larger ones.

It is important to realise that the bundles in the stem are continuous with the veins of the leaves on one hand and with the veins in the vascular cylinder of the root on the other.

(a) Soak the stem of a Broad Bean or Dead Nettle (try other herbaceous Dicotyledons) for two days in dilute potash, and then for two days in dilute nitric acid. Brush and scrape away the softer parts, leaving a skeleton of the vascular tissue. Note the way in which the bundles from the upper leaves join on to those of the lower leaves.

(b) Another method of showing that the vascular bundles (veins) of the leaf are continuous with those in the stem is to cut thick longitudinal slices through the stem and the bases of the leaves, and place the slices in caustic potash.

(c) To observe the continuity between the bundles of the stem and those of the root, split a Bean seedling longitudinally in the part where stem and root meet, and treat with caustic potash or aniline chloride solution*; the former makes the soft tissue transparent, the latter stains the hard woody tissue yellow.

(d) The Vegetable Marrow (or the Cucumber) is one of the most suitable plants in which to study the tissues of the stem. Cut across the middle of several "internodes" in the older parts of the shoot, and in each piece thus obtained notice that (1) the "node" gives off a leaf, a special climbing organ (tendrils), and usually either a leafy branch or a flowering branch, or both; (2) the internode is hollow, so that the stem forms a tube, with (usually) five ridges, and furrows alternating with these; (3) the bundles (usually ten) are arranged in two rings.

Scrape gently the outer surface of the stem, and remove part of the epidermis or skin, which is thin and colourless and bears hairs, some of them large and prickly. Notice the soft tissue which lies between the bundles; this is the ground tissue (*parenchyma*), and its cells can easily be seen with a lens. After removing the epidermis, scrape away the soft tissue which lies below it, and notice the hard tissue, which forms a wavy tube around the stem, outside of the bundles. Slit a piece of stem by two longitudinal cuts, and by scraping isolate a strip of this hard tissue (*sclerenchyma*). Bend it, pull it by the two ends, and try to split it; notice that it is easily split longitudinally, but is

* Dissolve some aniline chloride (about $1\frac{1}{2}$ d. per ounce) in a little alcohol, add water to make a 10% solution, then a little hydrochloric acid. A wooden match, or a splinter of wood, turns bright yellow after being dipped into the solution, which gives a ready test for woody substance (*lignin*).

difficult to break by pulling at the ends. This hard tissue, then, is fibrous, very strong, and it gives mechanical support to the stem; it is really a part of the ground-tissue, which has become fibrous and hard.

(e) Now examine the bundles which are embedded in the soft ground-tissue within the sheath or tube of hard tissue. Notice in each bundle (1) a whitish hard portion, consisting chiefly of tubes of various sizes, and occupying the centre of the bundle; (2) two greenish soft portions on the inner and outer sides of the hard portion. Place a piece of the living shoot with its cut end dipping into red ink, and notice that the ink rises in the middle portion of each bundle. This portion is the *wood*, and the tubes it contains are the *vessels*, which carry water upwards from the root. Split a long piece of stem so as to get a strip containing a single bundle; put one end into a glass of water and blow through the other, noting the air which escapes in bubbles after passing through the vessels. This shows that the vessels are long, open tubes.

(f) Next cut across a piece of fresh stem with a dry knife or razor, and notice the juice which oozes out of the soft greenish outer and inner portions of each bundle. These portions are the *bast*,* and they also consist chiefly of tubes; but the bast-tubes, instead of carrying water up the stem as the wood-tubes (vessels) do, carry organic food-substances from the leaves to other parts of the plant. Notice that the juice which oozes out of the bast-tubes is thicker than water; collect some of it, place it on a glass slide, and test it (1) for starch, (2) for proteids, (3) for sugar. To test for (1) and (2) add a drop of iodine solution; for (3) place some Fehling's solution on the slide with the juice and warm it, or collect enough juice to place in a test-tube and heat with some Fehling's solution.

173. Structure of the Root.—The root, like the stem, contains vascular bundles, but the wood-bundles are separate from the bast-bundles and lie on alternate radii, whereas in the stem the wood and bast are joined to form each bundle. The vascular cylinder of the root contains from two to about eight bundles of wood and an equal number of bast-bundles in Dicotyledons, while in Monocotyledons the number of bundles is generally much larger.

Cut transverse and longitudinal sections of the main root of Broad Bean or Scarlet Runner seedlings, stain with aniline chloride, and examine with the microscope. Note the yellow-stained wood-bundles (usually five in Broad Bean and four in Runner); the bast-bundles alternating with the wood-bundles are not so easy to recognise clearly.

* The Marrow, Cucumber, and some other plants are exceptional in having bast on the inner side of the wood as well as on the outer side. In most stems the bast occurs only on the outer side of the wood. The bast-tubes are called *sieve-tubes*, because they are interrupted by cross-walls which are perforated like a sieve (*sieve-plates*).

The wood contains vessels and the bast contains sieve-tubes, as in the stem-bundles. The vascular cylinder is surrounded by a sheath, and outside of this is the cortex whose cells often store food besides conducting water from the root-hairs to the vessels in the wood-bundles.

The sheath around the vascular cylinder is very important, since part of it gives rise to the rootlets, besides helping to produce the secondary thickening of the root and also (usually) producing the cork-forming layer (cork-cambium). Each rootlet arises as a swelling of the sheath just outside a wood-bundle; as the root grows it partly pushes and partly eats its way to the surface. Do you see why rootlets are arranged in definite longitudinal rows on the parent root?

174. Growth in Thickness.—In almost all Monocotyledons the older parts of the stem are hardly any thicker than the younger ones near the growing apex. This is because the stem of a Monocotyledon usually does not undergo any continuous increase in thickness after growth in length has ceased. In Dicotyledonous shrubs and trees, however, a complete layer of growing tissue or *cambium* is present outside the wood but inside the bast, and each year this forms a new cylinder of wood outside the older one, also producing new bast within that previously formed. What are (1) the mechanical, (2) the nutritive, necessities which are met by "secondary thickening"? Remember the conducting functions of the wood- and bast-tubes, also that the fibres give strength, while the ordinary (living) cells store food.

175. Annual Rings of Wood.—In a cross section of a tree trunk or a thick branch,* a series of concentric rings (really, of course, *layers*) can be seen in the wood. Each of these rings corresponds (normally) to one year's growth.

The wood formed in spring has large vessels which are required for the rapid transport of water to the young leaves, and it is softer than the hard compact wood formed later in the year as the rapidity of growth decreases and the leaves transpire and assimilate less and less actively. In autumn the formation of new wood ceases, reserve foods are stored up, and the resting-buds (Art. 185) are usually by this time (about the end of August) fully developed. In spring the buds open and the young leaves expand: the cambium, being well

* Old *roots* undergo growth in thickness (beginning in a rather different way), just as stems do, and show annual rings.

supplied with food, again begins to grow actively and to form new spring wood. The transition from spring to autumn wood may be gradual, but there is an abrupt change from the autumn wood (containing narrow vessels) of one year to the spring wood (containing wide vessels) of the next. Various causes which bring about fluctuations in the amount of food or of water supplied to the cambium may be responsible for the occasional production of several "annual" rings in one year; for instance, an extra "ring" is formed when the early leaves of trees are damaged (by frost, cold dry winds, insects, etc.) and "Lammas shoots" (more correctly "midsummer shoots") are produced (Arts. 187, 189).

176. Rays.—Running outwardly from the centre of the stem are numerous bands, the medullary rays,* which serve partly for the storage of starch and oil, and partly for the horizontal conveyance of food materials and water. They also serve to bind together the successive layers ("rings") of wood, and thus make the wood compact and strong. The rays are vertical plates; their height varies, but they must not be thought of as sheets of tissue running continuously from the base of the stem to the apex. The rays can often be seen very plainly on a square Pine match; two opposite faces show the rays as broad, shiny, horizontal streaks (radial faces), while on the other two (tangential) faces they appear as narrow vertical streaks.

177. Heart-Wood and Sap-Wood.—In old trees showing *many* annual rings, the central region of secondary wood is often distinctly marked off from the outer region. This is largely due to the wood-cells losing their contents and to changes in colour and in chemical composition of the walls of the wood-vessels. The central region (heart-wood) is harder and darker than the peripheral region (sap-wood).

It is almost entirely by means of the young sap-wood that water is conveyed upwards from the roots to the leaves. As

* The rays, though called medullary or pith rays, do not all extend into the pith; most of them stretch from the cambium to an annual ring (additional rays are formed each year).

the wood grows older it becomes unable to act as a channel for the passage of water. Hence the importance of the addition of new layers of wood is two-fold: first, it provides a connected series of new channels for the ascent of water as the old ones become functionless; and secondly, it increases the strength of the stem as the weight of the upper portion of the tree increases.

178. Knots.—The knots which occur so commonly in the wood of trees are the bases of branches which have become surrounded by the new layers of wood produced as the stem increased in thickness. Carefully examine logs of various kinds of wood, and find out all you can about the history and mode of formation of the knots.

Do the knots run right through the tree-trunk from outer surface to centre? What has probably happened, and how many years ago, when the knot ends abruptly and is covered on the outer end by the new wood-layers? How does "Bird's-eye Maple" get its name, and what are the "eyes" in its wood? Why is a knot usually much harder than the rest of the wood? Why does a knot often fall out very readily from a plank or board?

179. Cambium.—The chief function of the cambium is to produce new tissues. The cells of the cambium-layer are living and capable of active growth and division, the new cells formed being mostly converted into new "water-tubes," new "food-tubes," and new fibres, while some remain comparatively unaltered (beyond growing in size and changing in shape) and add to the living cells present in wood, bast, and rays.

The shoot is continually growing and producing new leaves and buds, so that year by year the number of leaves is becoming larger. This involves a yearly increase in the weight of branches and leaves to be supported and spread out to light and air. The branching of the root means a continually growing area of absorbing surface, in the form of root-hairs, in the soil, and since the root can make no organic food to supply its increasing needs, more and more leaf-manufactured food must be conveyed to it.

All this means an increasing demand for more wood-tubes to conduct water and salts from the roots, more bast-tubes to conduct organic food from the leaves, more strengthening tissue (fibres, which act solely as strengthening structures, and wood-tubes, which serve this purpose in addition to that of conduction), and more tissue in which food can be stored (*e.g.* the rays).

It is obvious that this important zone of growth is most favourably placed in the plant. It is well protected from external influences, and

well supplied with necessities of life. On its immediate inner side are the wood-vessels along which the water and inorganic salts pass from roots to leaves; while touching it on its outer side is the bast through which manufactured food materials are sent for distribution throughout the plant. Moreover, running through the cambium are the medullary rays, from which the cambium can draw supplies of food when, as in the early spring, no new food is being made by photosynthesis.

Besides the functions mentioned above, the cambium plays other parts under certain conditions. It is involved in the processes of **grafting**, propagation of plants by **cuttings** ("slips"), and in the healing-over of wounds on the stem.

180. Cork and Bark.—It is evident that the internal formation of secondary wood and bast must exert considerable pressure on the outer tissues, which are stretched and eventually ruptured. To provide for this there is the formation of new tissue from a growing layer developed in this region. This layer is the **cork-cambium**. In the majority of cases this cambium arises in the outermost layer of the cortex, immediately below the epidermis. The young cells given off to the outer side of the cork-cambium form a tissue known as **cork**. This tissue, being impermeable to water, cuts off the epidermis from nourishment. The epidermis dies and gradually peels off as the first bark of the tree. The cork is developed to replace the epidermis and carry on its functions.

181. The Bark may be defined as the dead tissue lying outside an active cork-cambium. We have already indicated what the first bark consists of. The first cork-cambium formed may persist for a large number of years, or even throughout the life of the tree. In such cases, *e.g.* Birch, Beech, there may be a considerable formation of bark owing to the dying off of the older cork-layers. But in most cases this first cork-cambium dies, sooner or later in those plants where it has a superficial origin, early in those where it is deep-seated. It is replaced by a new cork-cambium developed in the deeper tissue. This produces a new cork-layer, and as a result all the outlying tissues (the original cork, etc.) die and are added to the bark. If the succession of secondary cork-cambiums is rapid, it often happens that the cork comes to lie close to the bast, and in some cases the new cork may even arise *in* the bast, *e.g.* Vine and Clematis.

In some trees the bark comes away in sheets, and is spoken of as **ring-bark**. This may be due either to the first cork-cambium being persistent or to the successive cork-cambiums appearing in the form of regular rings. But in most trees

the bark is given off in scales (**scale-bark**); this is due to the fact that the secondary cork-cambiums do not arise as regular rings or layers, but in the form of curved strips.

182. Lenticels.—In the young green shoot the epidermis has stomates allowing for the free entry and exit of gases. When the cork-tissue is developed we usually find certain structures known as lenticels, which usually form small oval patches on the surface of the shoot. In Birch the lenticels are long, transverse, and very conspicuous on the white bark. Sections show that at these points the cork-cells are not in close contact, but have separated from each other and form a loose powdery mass through which gases can readily pass.*

These lenticels are as a rule developed immediately underneath the stomates. Where a thick mass of cork is developed they form long passages or canals, filled with the powdery cork-cells, as, for example, in the ordinary cork of commerce.

183. Practical Work on Woody Stems.—

(a) Cut sections of twigs of Elder, Willow, Elm, Oak, or other trees, and notice in the youngest parts the separate bundles arranged in a ring. In the older parts note that the continuous cambium has produced a solid mass of wood on its inner side, while the surface of the stem has become covered by a brown coating of cork. Peel off the cork, and notice the green cortex, then a zone of colourless tissue (bast), which is separated from the hard wood by a moist sticky layer (the cambium). Cut sections and stain some with aniline chloride, others with iodine. In the wood, notice the rays and the "rings." Look for trees showing stages in healing of wounds where branches have broken off. Compare the wood of various common trees; make a collection of polished slices. Find out all you can about timbers—density; hardness; uses; "silver-grain"; "burrs"; "shakes"; canker, dry rot, and other diseases, etc.

(b) Next cut a thin slice out of the thickest part of a branch with a saw, and rub down one of the cut surfaces on fine glass-paper until it is very smooth. Examine it with the aid of a lens, and note the parts as indicated in the preceding paragraphs (Arts. 175-182). Examine logs of wood showing the cut surfaces, or the cut stumps of trees in a wood or plantation.

(c) Strip the cork-layer from twigs of Elder and other plants which show lenticels plainly on the surface, and notice that lenticels are not merely surface-marks, but that they pass right through the cork to

* There are air-spaces between the cells forming the medullary rays, so that air can pass to and from these and other living cells in the wood, by way of the cortex and lenticels.

the green cortex-tissue. Strip off, layer after layer, the bark of a Birch twig, and notice that the lenticels go through all the layers.

(d) Dip a twig of Elder, Birch (or other plant which shows lenticels plainly) into boiling water, and notice the air-bubbles which escape from the lenticels. This shows that the green outer tissue of the stem has air-spaces, and that gases can pass through the loose lenticel-tissue.

QUESTIONS ON CHAPTER IV.

1. Describe simple experiments to show by what paths water travels through the plant from roots to leaves.

2. What are the main functions of roots? How are they adapted to carry on these functions?

3. How is the radicle of a seedling enabled to penetrate stiff soil? How may the force exerted by the radicle be measured?

4. How can it be proved that the direction of growth of a root is a response to the stimulus of gravity? Explain the term "geotropism."

5. How is the direction of growth of a root affected by moisture? Why is it advantageous to the plant that the stimulus due to moisture is able to overcome that due to gravity?

6. How is the direction of a root's growth affected by light? How does a shoot differ from a root in this respect?

7. How is the growth of a root-tip affected by contact with a hard obstacle?

8. How can you measure the rate at which root and shoot grow in length?

9. How can it be proved that the root-tip alone is sensitive to the stimuli of gravity, light, etc.?

10. In what part of a root does growth in length occur? How can it be proved that the curvatures in response to stimuli (gravity, light, moisture, contact) also occur in this part?

11. Describe the characters of the various regions of a root, starting from the extreme tip.

12. What are root-hairs and what is their function?

13. Why should a farmer keep his crops free from weeds? In what way are weeds harmful, if this is not done?

14. How do root-hairs help the root to absorb the water of the soil as thoroughly as possible? Under what conditions will root-hairs be (a) abundantly, (b) scantily developed?

15. What is root-pressure? How is it set up, and how can it be demonstrated and roughly measured?

16. What are the essential elements of an ordinary green plant's food? In what forms are these elements obtained?

17. What is meant by "water-culture"? Name the substances which are used in making up a culture-solution for a green plant.

18. How could you prove that nitrates (of soda, potash, or lime) are present in a fertile soil?

19. Explain how you would investigate the rate of growth in length of a root, indicating the precautions you would observe in conducting your experiments. Illustrate your answer by a diagram.

20. Show how some of the commoner operations of gardening, such as digging, manuring, raking, transplanting, and watering, may be conducted so as best to minister to the chemical and physical conditions of plant-life.

21. Describe the structure of the stem in any Monocotyledon, as seen in longitudinal and in transverse sections.

22. In what features of structure and function do the vessels of the bast (sieve-tubes) differ from those of the wood?

23. What is a vascular bundle? Of what parts does a vascular bundle in the stem of a Dicotyledon consist, and what are their respective functions?

24. Explain the structure, as seen in transverse section, of a twig of any Dicotyledonous tree.

25. State generally what is the composition of a vascular bundle. Describe the longitudinal course of the vascular bundles in the stem of any Dicotyledon.

26. What is the cambium? Explain where you would find it in the stem of a tree, and what is its importance.

27. What is meant by a "vessel"? What are the differences between the vessels of the wood and those of the bast?

28. What is a "growing-point"? What is the difference between the growing-points of stems and those of roots?

29. Describe the way in which the stem of a Dicotyledonous tree grows in thickness, and explain how it is that its wood shows annual rings.

30. The stem of an Oak tree continues to grow in thickness so long as the tree lives, whereas the stem of a palm-tree does not grow any thicker when once formed. Explain the cause of this difference.

31. Along what tissue does the sap ascend in a stem in its passage from root to leaf? How would you endeavour to prove by experiment the truth of your statement? What other movement of liquid substance takes place in plants besides the ascent of the sap, and what is the path of this current?

32. Explain as far as you can the way in which water is absorbed from the soil by the roots, and the transpiration current maintained, in the case of trees.

33. What method, other than watering, would you use to recover a plant, growing in the open, which had become flaccid from loss of water? Give reasons for the method adopted.

34. What are adventitious shoots? Under what circumstances are they most readily produced? Mention three examples.

35. Describe accurately an experiment which you have seen in which the rate of growth of roots or shoots was measured. Which part of the root grows most rapidly in length, and which part absorbs most water? What advantages do plants gain by the increase of their shoots and roots in length and thickness?

36. Why does a succulent flower-stalk or petiole lose most of its rigidity when cut and in want of water? Could you produce this condition artificially without exposure to the air? How would you attempt to restore the rigidity of a stalk thus artificially wilted? Give reasons for your answers.

37. Describe and explain the changes that may be observed when a shoot is bisected longitudinally, and when the halves are placed successively in water and in strong salt solution.

38. The trunk of an Oak tree, when in full leaf, is sawn all round so deeply as to cut through the sap-wood. State and explain the effect of this operation.

39. Explain the nature and mode of origin of "knots" and of "silver grain" in timber.

40. What is meant by a Medullary Ray? Where are medullary rays found, and what are their uses?

41. When the trunk of a Dicotyledonous tree is cut across, the wood is seen to be disposed in rings. Explain this fact, and indicate its relation to the age of the tree.

42. Explain why it is easier to split a piece of wood in the direction of the grain than across it.

43. Give an account of the structure and uses of Lenticels.

44. Describe and explain as fully as you can the appearance assumed by a tree growing in a position fully exposed to the wind (near the sea or on a hill-top or ridge).

45. What is starch? Where do you find it in the plant? How would you recognise its presence in a plant (*a*) with the naked eye, (*b*) under the microscope? State exactly what you know of the part played by starch in the economy of the plant.

46. Give the outlines of a lesson on Transpiration, and state exactly what experiments you would perform, and the conclusions you would draw from each.

47. What materials would you select for the purpose of demonstrating the various modifications of stems, and how would you explain the morphological nature of the objects to a class?

48. What are the chief points on which you would lay emphasis in a lesson on Turgescence? By what experiments would you illustrate the lesson?

49. Explain fully what is meant by Bark, and state the various ways in which it may be formed.

50. What use could you make of the botanical material provided by a vegetable shop during the winter months *e.g.* Carrot, Turnip, Potato, Beetroot, etc.—to illustrate the form, structure, and living processes of plants?

CHAPTER V.

BUDS.

184. Buds.—Before the young stem branches, it is in most cases easy to see that between the base of each leaf and the upper portion of the stem there is a young bud (*axillary* bud or side-bud), which may grow into a shoot bearing leaves only, or flowers only, or both leaves and flowers. The apex of the stem is usually occupied by a *terminal* bud (end-bud).

Buds appear as little prominences on the outer surface of the stem, and are produced by outer tissue, whereas secondary roots arise from *within*. Each bud consists of a short “condensed” stem in which the “internodes” are undeveloped, so that the young leaves are closely packed together. The formation of a bud depends on the fact that the slowly-growing end of the shoot elongates less than the leaves which it has produced, and these bend over its tip and protect it. The apex of the stem of the bud is occupied by a growing-point, which grows and elongates when the bud opens; since it is not exposed to friction against the soil, there is no need for any such structure as the root-cap, which covers and protects the growing apex of the root.

185. Winter-Buds (Resting-Buds).—In cold climates the buds formed at the close of the year do not develop at once, but remain dormant after the leaves have fallen. When a resting-bud is about to be formed, the last foliage-leaves on the shoot sometimes grow in the ordinary way, but the stem stops growing and these leaves enclose the young leaves formed inside the bud. Naked resting-buds of this kind occur in herbaceous plants, their structure being essentially

like that of a Brussels Sprout, Lettuce, or Cabbage, but only in a few woody plants (shrubs and trees), *e.g.* Ivy, Bittersweet.

In most woody plants, however, the bud is covered by special scales (*bud-scales*), each representing a leaf or part of a leaf and being usually thick, hard, corky, gummy, resinous, or hairy, and these scales protect the delicate and sappy young leaves within from injury by rain and frost, but especially from loss of water. In cold weather the roots are hardly able to absorb any moisture from the soil, so that loss of water at such a time, when there is little or no transpiration-current flowing up in the stem, would be fatal to the young shoot inside the bud. When a cold dry east wind comes after the buds have expanded in spring, the young leaves are often killed, whereas an equally cold but moist westerly wind hardly affects them.

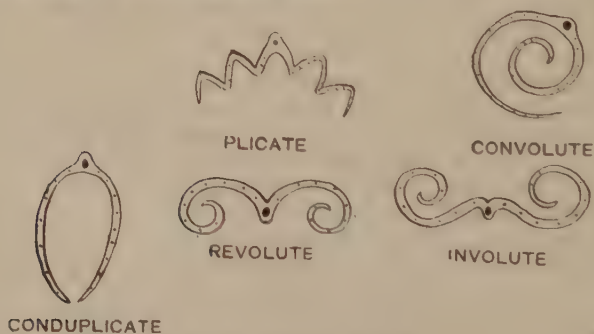


Fig. 36.—Vernation of Leaves.

The scales of resting-buds may represent whole leaves (Privet, Lilac), leaf-bases without stalk or blade (Sycamore, Horse-Chestnut), stipules of leaves which develop a blade (Alder, Elm, Hazel), or stipules of leaves which do not develop a blade (Oak, Beech).

To ensure the close packing of the leaves in the bud each one is usually rolled up longitudinally (more rarely rolled up transversely); but sometimes the leaves are nearly flat, *e.g.* Privet, Holly, Ivy, Willows. Dealing only with longitudinal folding, the leaf may be simply doubled on itself along the midrib (Fig. 36, *conduplicate*), or it may be pleated so as to resemble a fan (*plicate*), or the edges of the leaf may be rolled inwards (*involute*) or outwards (*revolute*), or the leaf may be rolled

up from one side, so that one leaf-margin is within the coil and the other outside (*convolute*). The young leaves are conduplicate in Cherry, Rose, Elm, Hazel, Oak, Lime, Ash; plicate in Maple, Sycamore, Birch, Beech, Hornbeam; involute in Poplars, Apple, Pear (also in Violet); revolute in Plane and Rhododendron (also in Docks); convolute in Plum and Sloe (Blackthorn).

In spring or early summer the winter-bud resumes its development. The young shoot grows and lengthens, pushing aside the bud-scales, which then fall off. Since each scale leaves a scar on the lower part of the bud-axis and this part remains short, a series of closely-set scars is left on the stem. A series of bud-scale-scars ("girdle-scars") is of course seen at the base of each branch, and by examining a twig and noting these series of scars we can easily tell how much the twig has grown each year, often for many years back; later on these marks are obliterated by the formation of bark, but in smooth-barked trees (*e.g.* Beech) one can trace the growth back for thirty years or even more by these girdles of scars.

As the bud-axis elongates, the leaves grow in size and spread themselves out (the leaf-stalks of course helping in this, if present), becoming spaced out on the young shoot. Buds then appear in the axils of the leaves, and these may either develop at once or after remaining dormant for a time, some of them of course becoming the resting-buds for next year's growth.

It is easily understood why *all* of the axillary buds do not usually develop into branches, for if they did the foliage would be too closely packed together, and sufficient light and air* could not reach all of the branches and leaves. As we shall see later, trees differ very much in their mode of branching and in the arrangement of their leaves; thus in the Horse-Chestnut and the Beech the outer leaves are densely packed together, so that buds within the crown of foliage have but little chance of developing into leafy branches, owing to the small amount of light which reaches them. In the Birch and Larch, however, the foliage is more open, and the buds nearer to the stem have perhaps as good a chance of developing as the buds at the tips of the branches. These points will be illustrated by the various common trees which we shall study.

* See Art. 153. This, as well as other parts of Chapter III., should be kept in mind and continually referred to in your work on trees and other plants.

Whenever any of the branches are pruned away or broken off by high winds or by the weight of snow, buds develop which would otherwise have remained dormant, and in this way trees are able to rapidly fill up gaps in their canopy of foliage. So also pollarded willows soon form a crown of new shoots, and many of these arise from deep-seated buds, or from *adventitious* ones. The latter are buds which develop out of their normal order, or without any relation to the leaves. Adventitious buds may be formed not only upon the stem, but also on roots or leaves. Some Begonias are artificially propagated by placing sliced leaves on damp soil; buds appear on the wounded edges, strike root, and develop into new plants. Adventitious buds may appear on the roots of the Hawthorn, Dandelion, and other plants, and may give rise to leafy or even flowering shoots. For example, the roots of the Hawthorn, if chopped into small pieces and covered loosely with damp soil, produce buds and ultimately new plants. Most people are familiar with the fern-like shoots produced when the top of a Carrot (partly stem, partly root) is cut off, scooped out, filled with water, and hung up by strings; try this simple experiment for yourself.

186. Brussels Sprout.—To get a good idea of bud-structure, first examine some Brussels Sprouts. (1) Pick off the leaves one by one, starting from the outside, and note that each leaf has a small bud in its axil. How do the inner leaves differ (in size, form, texture, colour) from the outer ones? How may these differences be accounted for? (2) Slice down through the middle of another sprout, and notice the conical end of the stem, with small outgrowths at its extreme tip; these outgrowths are the youngest leaves. Below these are older leaves, gradually becoming distinctly divided into blade and stalk; lower still come leaves whose blade is folded between the veins. In the axil of each leaf is a small bud, resembling a miniature sprout; some of these buds may be cut through in the slice (if not, make more slices). Notice the strings (veins or vascular bundles) in the stem of the Sprout. Sketch a good clear longitudinal section, at least the natural size. (3) Cut a series of *cross* sections, beginning at the top of the Sprout and proceeding to the base; lay the sections out in order, then compare and sketch them. (4) Set a Sprout with its cut end in red ink, and after a time cut slices and notice the bundles which extend nearly to the extreme tip of the stem and give off branches to the leaves and buds. (5) Remove most of the larger outer leaves, and notice that the inner ones soon become wilted if the sprout is set in a dry place. (6) Weigh (*a*) an entire sprout, (*b*) one from which all the large outer leaves (which overlap and

protect the young inner ones) have been removed; set both in a dry place, and in a few hours, or a day, weigh again and compare the loss in weight in the two cases.

Lettuces and Cabbages may be used in addition to Sprouts. Why are the inner leaves softer and lighter-coloured than the outer leaves? What other differences do they show?

187. Sycamore (see Art. 307).*—Examine twigs at different times of the year, noting the arrangement of the

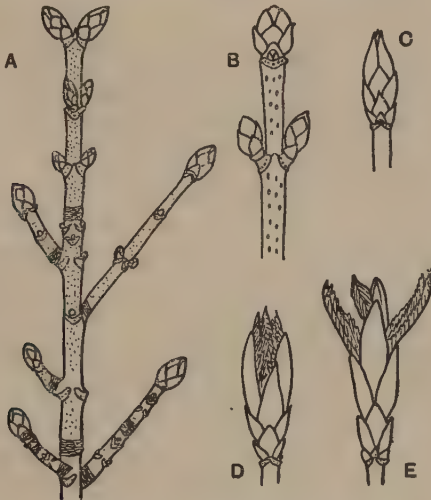


Fig. 37.—Twigs of Sycamore and Stages in Opening of Bud.

leaves, and therefore of the axillary buds, in crossed pairs, forming four rows on the stem (Fig. 37). The twigs are, in the younger parts, grey-green to yellow-brown in colour and

* If you do not know these trees in their winter aspect, cut twigs and put them into bottles or jars of water and keep them in a warm room; in many cases the buds will open, since warmth hastens growth. In this way you can study very conveniently the unfolding of buds (sketch the stages observed) and at the same time identify unknown trees or shrubs by the leaves in many cases.

are dotted with small lenticels. The leaf-scars are shallow, V-shaped, with three slight projections (bundle-scars). The buds are egg-shaped, with four projecting ridges owing to the boat-like form of the bud-scales. The scales, which are arranged in opposite pairs, overlapping each other regularly, are greenish below and brown at the tips and around the edge. The large end-bud, which generally has two small side-buds just below it, frequently contains an inflorescence in addition to young foliage-leaves.

Dissect a bud, carefully removing the parts and laying them out on a sheet of paper. Note that there are six or seven pairs of scales altogether, though only four or five pairs are, as a rule, visible on the outside of the bud. How do the inner scales differ from the outer ones in colour and texture? Examine the tips of the scales: do any show here a small undeveloped leaf-blade, with three or five lobes? To what part of an ordinary foliage-leaf—the leaf-base or the leaf-stalk—does the bud-scale correspond? Note the young foliage-leaves in the centre of the bud: how many are there visible, and what portions of the leaf are already developed? Note the fan-like manner in which the young leaf-blade is folded; try to cut out from a sheet of paper a model of the young blade. Is the young leaf smooth and bare, or has it any protective covering of hairs?

Cut buds through, some longitudinally and some transversely, to see how the leaves inside are folded up.

In spring, notice how the buds swell up. Make careful observations on the opening of the buds. It is possible to cause them to open in winter by setting a cut twig in water and keeping it in a warm room. Notice how the inner scales, as well as the young foliage-leaves, expand and lengthen, pushing aside the outer scales, and how the young leaves unfold themselves. The buds open at end of April or early in May.

Make notes and sketches of all the stages in the opening of the bud. Note that the stalks of the young leaves, which have hitherto been very short (how does this prove that the bud-scales are leaf-bases and not stalks?), rapidly lengthen and carry out the leaf-blades beyond the scales. Note that the lower part of the stem of the bud hardly lengthens at all, so that when the bud-scales fall off they leave a number of crowded scars, while the upper part of the bud-axis grows out to form a long or short shoot, the leaves becoming spaced out (in pairs) upon it.

Now look backwards along the twig, to find the place where *last* year's end-bud was: how does this enable us to see exactly how much the twig grew each year, at least for several years back? Why is it that a series of these "girdle-scars" or bud-scale-scars is always found at the base of a side-twig, where it joins the parent-twig? Does a twig always grow equally long, or bear an equal number of foliage-leaves, every year? In the case of a horizontal branch, which buds grow into the most vigorous (as regards length of stem and number of

leaves) twigs—the upper ones, the lower ones, or those on the flanks of the branch? Why do you suppose the horizontal branches differ in this respect from those which are erect or nearly so? If you recall your studies of the work of leaves, you will probably conclude that *light* is the chief factor concerned, but you should stop and think the matter out. If you cut off a horizontal branch and set it erect in water, how do the four rows of buds behave after opening?

At what time of year are the resting-buds *formed*? Can you see any trace of them, in the axils of the new leaves, just after the bud has opened and the young shoot has grown out? Notice how the buds grow in size during the summer.

Is it possible to cause the young buds to grow out at once instead of resting until next spring? Try the effect of pulling off the leaves from a twig; the buds may thus be caused to grow out a year before the proper time. This precocious growth of buds is sometimes seen in the Sycamore and several other trees, owing, in some cases at least, to external causes (*e.g.* a late period of wet weather preceded by a dry early summer and followed by a mild autumn, or the early dying of leaves through dry cold spring winds, or attacks of insects), or simply to excess of food; these “Lammas shoots” are often seen on Oaks, Beeches, Horse-Chestnuts, etc. In these cases leaves which had arrested their growth in order to form bud-scales resume growth and become foliage-leaves, bearing resting-buds in their axils.

188. Horse-Chestnut (see Art. 309).—The arrangement of leaves and buds on the stem, and the general structure of the buds, are the same here as in the Sycamore. The twigs (Fig. 38) are thick, smooth, grey or brown, with conspicuous lenticels. The large leaf-scars vary from being shield-shaped to half-moon-shaped, with scars of from five to nine bundles. The uppermost bud is generally larger than the others and contains a young inflorescence in addition to young leaves, but the true end-bud is often missing and represented by the saddle-like scar of the fallen inflorescence.

The buds are egg-shaped, pointed, brown, shiny, and sticky. Remove the hard concave scales, which are more or less cemented together by the sticky substance. Note the arrangement of the scales in pairs, set at right angles to form four rows; the two lowest (outermost) scales are smaller than those of the next pair, and these are again smaller than the third pair, then come two or three pairs of still larger scales which cover the top of the bud. Within these we see a pair, or two pairs, of soft greenish sticky scales, each often having at its tip five little lobes; then come the foliage-leaves, covered with down and folded up. While dissecting the bud, keep dipping it into alcohol to make it less sticky and easier to examine. How many young leaves are visible? In the large uppermost buds the axis is prolonged above the young leaves and bears numerous young flowers in tufts.

When the bud is about to open it swells up considerably, then the scales become loosened, the inner scales grow up and bend outwards, and the young leaves emerge with the leaflets (how many to each leaf?)

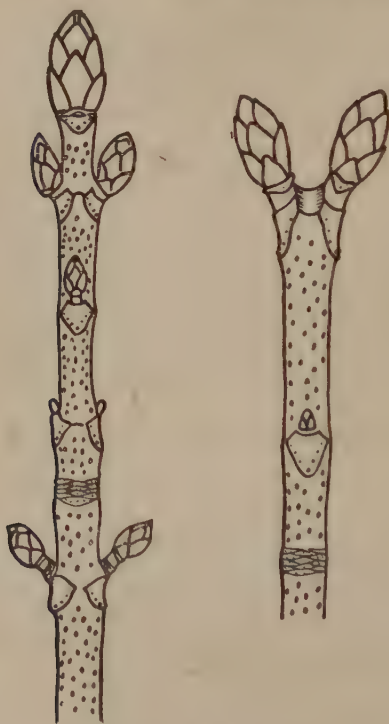


Fig. 33.—Twigs of Horse-Chestnut.

erect, each leaflet being folded along the midrib and the side-veins as well. As the leaf-stalk lengthens (the leaflets are sessile on its end), the leaflets spread open and bend downwards. Later, the leaflets rise up again and spread out horizontally; meanwhile the stem of the bud has been growing in length. The bud-scales fall off; the white hairs covering the leaflets become brownish and fall away.

Here, as in Sycamore, it is easy to see, as the bud opens, that the structures lying between the hard, externally visible, scales and the

young foliage-leaves are intermediate in nature between bud-scales and ordinary leaves. The buds usually open about the middle of April.

189. Oak (see Art. 304).—Here the leaves and buds are arranged singly and spirally on the grey or brown twigs (Fig. 39). In passing from any leaf, or bud, to the next one directly above it, we go twice round the twig and pass four



Fig. 39.—Twig of Oak and Ground Plan of Bud.

other leaves, or buds; there are therefore five rows of leaves, as can generally be seen on looking along the twig. The buds, which are crowded at the tips of the twigs, are brown, smooth, egg-shaped, and slightly five-angled. The clustering of the buds towards the tip of each twig is of course simply due to the upper leaves being clustered in this way so as to form a rosette. The leaf-scars are small and triangular, with numerous bundle-scars; the lenticels are small and scattered.

Examine a bud and notice that it begins with a few tiny thick scales at the base; then come about twenty thinner scales, arranged in five rows and becoming more delicate, as well as narrower, as they pass

inwards. Then come the young foliage-leaves; the outer ones are very small, each being flat and standing between two stipules, while the inner ones are larger and folded along the midrib (conduplicate), and finally come small ones again in the centre of the bud. Careful examination shows that the bud-scales, after the two lowest, are arranged in pairs; this fact suggests that these scales are *stipules*, and, by observing the opening of the bud and also the way in which the bud is formed, one can prove that this is the case. Towards the end of the summer the last leaf-structures to be formed are stipules, which persist and become the outer bud-scales; the uppermost complete leaves are crowded and each forms a bud in its axil. The buds open in May.

As a rule, the lower resting-buds on a twig remain dormant, and do not open in the spring of the year succeeding that in which they are formed. The Oak is a light-loving tree and tends to have its leaves in rosettes at the tips of the branches so as to catch as much light as possible. Taking the case of a complete flower-containing bud, as soon as the bud-scales become loosened the male catkins, which arise in the axils of the upper bud-scales, grow out first and hang downwards, then come foliage-leaves (each with a young resting-bud in its axil), then leaves with groups of female flowers in their axils, and then again leaves with axillary buds. After the young shoot has grown out of the bud, the resting-buds towards its tip generally open in late summer, forming a second generation of leafy shoots ("Lammas shoots").

190. Scots Pine or "Scotch Fir" (see Art. 312).—Each twig (Fig. 40) shows, as a rule, an end-bud with a few (usually 3 or 4) side-buds just below it and forming an apparent whorl. One or more of the side-buds may be replaced by a seed-cone (Fig. 40 B). The buds open about the middle of May.

Examine a bud and note the very numerous (100 or more) scales, covered with whitish resin and arranged spirally. Each scale (except the lowest ones) bears in its axil a small bud, so that the resting-bud of a Pine is clearly a "compound bud"—a bud of buds. The lowest scales (those without axillary buds) are hard and remain at the base of the young shoot into which the resting-bud grows. Each of the other scales is at first green below and membranous above, with pointed tip and fringed edges, but when the resting-bud opens the base of the scale hardens and the upper part falls off.

The axillary buds on the "compound" resting-bud are the buds of the dwarf shoots which are so characteristic of Pines. Each bears about ten scale-leaves which form a sheath around two young foliage-leaves ("needles"), set face to face.

When the resting-bud unfolds, the pairs of green needles emerge from the axils of the scales as the shoot grows out; the needles grow in size, and the scaly sheath persists around the base of each two-leaved dwarf shoot. When the shoot stops growing in length, it shows

at the tip a terminal resting-bud and a circle of lateral resting-buds just below it, ready for next year's growth. The lateral resting-buds grow out just like the terminal one, at first growing more or less parallel with it but later bending away from it.

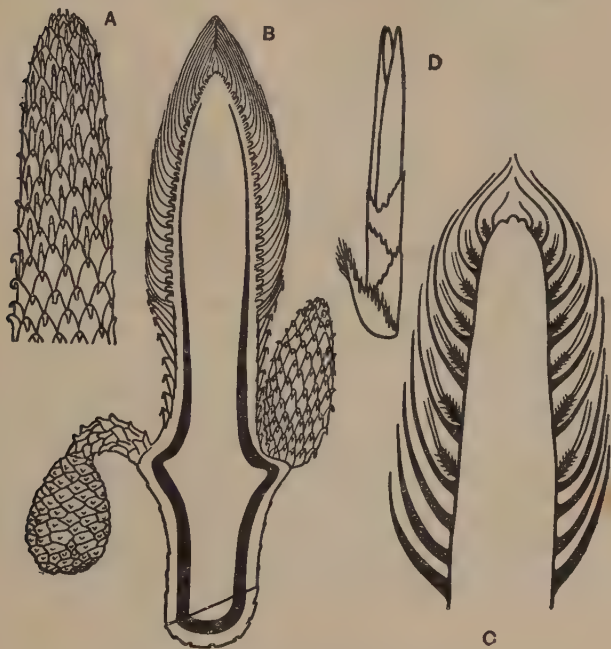


Fig. 40.—Scots Pine.

A, Bud beginning to open; B, Longitudinal Section of End-Bud (a Side-Bud is shown on right, a Cone on left); C, Diagram of Longitudinal Section of Bud; D, Young Dwarf Shoot.

191. Larch (see Art. 314).—The brown buds, covered with resinous scales, are found at the end and also scattered along the sides of the long shoots, which are green to brown, angular, and furrowed; the lateral buds are seen (in winter) in the axils of the leaf-scars, each of which is on a projecting leaf-cushion and shows a small bundle-scar.

Note that the end-bud of a long shoot is egg-shaped, while the side-buds are nearly globular. Each of the dwarf shoots—the short stout branches so characteristic of the Larch—has a bud at its end (Fig. 41). The bud-scales have fringed edges; the outer scales are triangular and the inner ones thinner, broader, and more rounded, then come the narrow green foliage leaves.

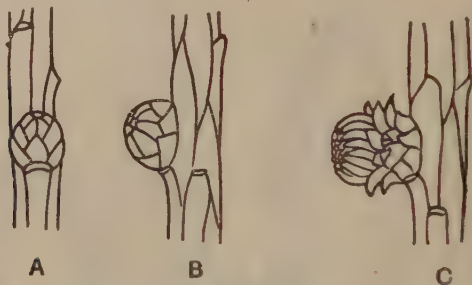


Fig. 41.—Larch.

A and B, Resting Bud; C, Bud beginning to open.

When the bud opens, the more delicate inner scales fall off, but the harder outer ones persist, and the light-green leaves grow out. Then the end-bud and some of the side-buds below it grow out to form long shoots, while the others remain short and form dwarf shoots. Dwarf shoots may repeat the process year after year, only elongating about $\frac{1}{8}$ inch or so each year, or they may at any time suddenly grow out to form a long shoot. The dwarf shoots only differ from the long shoots in having a very short stem with crowded leaves, instead of a long stem with leaves spaced out singly on it. The buds open about the middle of April; the flowers appear a few weeks earlier.

QUESTIONS ON CHAPTER V.

1. How can you distinguish by the aid of bark, buds, and general appearance between any six native British trees in winter?
2. Describe, with sketches, the stages seen in the opening of a Horse-Chestnut bud in spring.
3. Why are the buds of Scots Pine called *compound* buds? Describe the structure and mode of opening of a Pine bud, giving sketches.
4. Explain why one can tell how much a Pine branch has grown each year.
5. How can you tell the nature of the bud-scales in different trees? Give examples.

6. How can you *hasten* the opening of buds? Which buds have you succeeded in getting to open before they would have opened out of doors, and how long before in each case?

7. Describe, with sketches, the external appearance of a branch of Sycamore or Horse-Chestnut, explaining all the features shown.

8. Explain how one can tell how much a Sycamore or Horse-Chestnut branch has grown each year.

9. Describe a branch of Oak as seen in winter. Why do the buds tend to be crowded at the tip of the branch?

10. Describe various ways in which the young leaves are protected in the bud. Why are they usually folded up? Give examples and sketches.

11. What kind of plant produces Brussels Sprouts? What *are* the sprouts, and in what position do they stand on the parent plant?

12. Describe the buds of Larch, and the way in which they unfold.

13. Why are Willows and Poplars "polled" or "pollarded"? What is the effect of this operation on the growth of the tree?

14. Why do not *all* the buds on a tree branch open in spring? Why do some buds produce long shoots and others very short ones? How could you make a short shoot (dwarf shoot) of, say, Beech grow into a long shoot?

CHAPTER VI.

FLOWERS, FRUITS, AND SEEDS.

192. The Work of the Flower.—We have already examined the Broad Bean flower,* and we have seen that after a time nothing is left of the flower except (a) the “young pod,” which becomes greatly enlarged and contains the seeds; and (b) the calyx, which remains as a cup round the bottom of the pod. Evidently the great work of the flower is the production of seeds. Are any other parts besides the pistil concerned in this work, and, if so, what share do they take in it? You have noticed the yellow powder (pollen) which is produced in the anthers and is set free when they open, and which is then found inside the keel and on the upper parts of the pistil (style and stigma). Has the pollen anything to do with the production of the ripe pod and its seeds? Would the pistil grow into a fruit, with seeds, if no pollen came into contact with it?

193. Effect of removing the Anthers.—Flowers which have not yet opened must be used in these experiments, because the anthers burst and shed their pollen at an early stage. Remove the anthers, making sure that you pick off the whole number, and that none of them have burst already. To prevent pollen from reaching the pistil from another flower, tie a small bag of paper or of fine muslin over the antherless flower, which must, of course, be allowed to remain on the plant. If the removal of the anthers has been carefully done, the flower will open much as usual. Treat several flowers in this way, in case any damage is done which might throw doubt on the results. Are any seeds formed? Leave some of the antherless flowers uncovered: do any of these produce seeds?

194. Effect of removing the Stigma.—You will have noticed pollen adhering to the upper part of the pistil, *i.e.* the style, especially

* See Chapter I. If flowers of Broad Bean are not available when this part of your work is begun, use those of some other allied plant—*e.g.* Sweet Pea, Gorse.

to the tuft of hairs and the little terminal process (stigma) just above it. Is this end part of the style the only part capable of receiving pollen? Open young flowers (with the same precautions as before) and remove the upper part of the style, cutting just below the tuft of hairs; cover some of these stigmaless flowers with small bags, and leave others exposed. Does this affect the result? To meet the objection that the removal of the stigma causes injury which might account for the result, try the effect of opening some young flowers and covering the top of the style with a small bit of plasticine.

195. Pollination.—The foregoing experiments show that ripe seeds are not produced unless pollen comes into contact with the upper part of the style—that is, unless pollination occurs. Will pollen from the anthers of the same flower suffice, or must the pollen come from another flower?

(a) Cover a young unopened flower with a paper or muslin bag, and see whether seeds are produced. Treat several flowers in this way, so as to have a number of results on which to base your inferences.

(b) Place pollen on the stigmas of newly opened flowers, using a fine brush; dip the brush into boiling water before using it again each time (to kill any pollen left on it). In some cases (A) place on the stigma pollen from the anthers of the same flower; in others (B) bring the pollen from another flower on the same plant; in others (C) bring it from a flower on another plant. In the two latter cases (B and C) the flower's own anthers must be removed before they have opened.

Simple experiments like these show that the Broad Bean can be **self-pollinated** (Art. 198), although self-pollination does not (in the author's experience at any rate) occur so freely in this plant as in various other cultivated plants of the Bean family (Sweet Pea, Garden Pea, etc.). In the latter plants, in fact, pollination regularly occurs before the flower-bud opens, so that abundant seed is set in the entire absence of insect-visitors.

196. The Essential Organs.—It is now obvious that the only parts of the flower directly concerned in, and essential to, seed-production are the stamens and the pistil. The lowest seed-plants (e.g. Pine, Larch, Yew, Cycads) have their young seeds exposed (on flat scales in most cases) to the air, instead of being formed within a closed chamber or seed-vessel, as in the Bean; and the stalks of the stamens cannot be considered as essential (they remain undeveloped in some plants). The essential structures appear, therefore, to be the anthers and the "young seeds." We know that in the Bean, as in other seed-plants, these "young seeds" do not develop into mature seeds, but perish like the rest of the flower, unless pollen-grains are placed on the stigma.

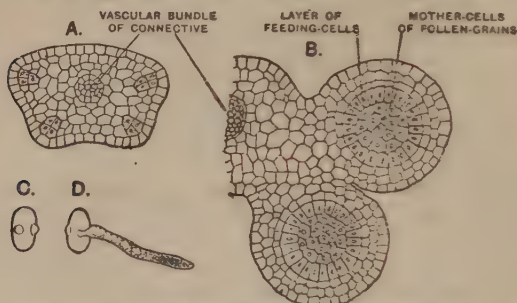
197. Fertilisation.—In what way does the pollen-grain

Fig. 42.—Broad Bean: A and B, Cross-sections of Young Anthers; C, a Ripe Pollen-grain; D, Pollen-tube.

induce the young seed to develop into a mature seed? What happens when a pollen-grain is placed on the stigma? We

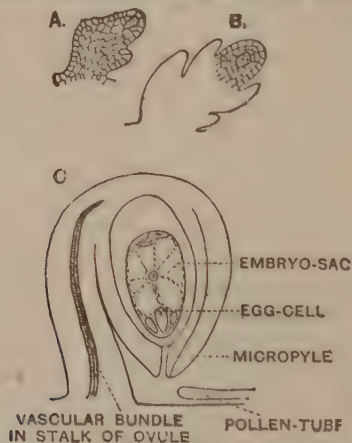


Fig. 43.—Development and Structure of Ovule ("young seed"), Longitudinal Sections.

cannot give a full answer to these questions unless we study the minute structure of the parts concerned.*

* For microscopic details of pollination, fertilisation, etc., see *Plant Biology*, Chap. VI.

In each "young seed" a cell, the *egg*, is produced. When the flower has opened the stigma becomes wet and sticky, so that pollen-grains are held on it. Each pollen-grain grows into a long fine tube which burrows down through the style and eventually enters the little opening in the "young seed" and its tip touches the egg-cell, which lies close to this opening, embedded in the "young seed" (Figs. 42-4). The pollen-tube opens, and a male cell passes from it to the egg-cell and fertilises it, *i.e.* fuses with it. Then the fertilised egg develops into the young plant (embryo); the part just outside of the embryo also grows to produce the endosperm, which may or may not be absorbed by the embryo before the seed ripens, the seed being non-endospermic ("ex-albuminous") in the former case, endospermic ("albuminous") in the latter.

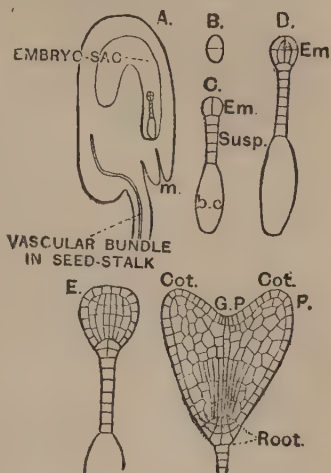


Fig. 44.—Development of Embryo in Shepherd's Purse.

A, Young Seed (treated with caustic potash) showing Embryo at micropyle-end of curved Embryo-sac; m., Micropyle; B-F, stages in growth of Embryo; G.P., Growing-point of Stem; Susp., Suspensor; b.c., Basal Cell; Cot., Cotyledon; Em., Embryo.

(a) Examine the stigma of a Tulip (or other flower with large stigma), and see whether it is wet. If so, shake over it some powder, *e.g.* flour or chalk, and then try to blow the powder off. Place a stigma on your tongue, and see whether it is sweet. Place a few stigmas in some Fehling's solution in a test-tube, and heat (test for sugar).

(b) Place some water in watch-glasses and add different amounts of sugar, so as to get solutions varying in strength from 5 to 20 per cent. Into each place some pollen; try various plants. In the case of the Broad Bean and the Sweet Pea a 10 per cent. solution is about right, and in an hour, or even less, you will see a slender thread growing from some of the grains; this is the pollen-tube, which resembles a root-hair in appearance (Fig. 42 D). If you have a microscope, fix a ring of cardboard or of plasticine on a glass slide; put a drop of sugar solution on a cover-glass, dust some pollen in it, then invert the cover

over the ring. The drop will hang into a closed chamber, thus preventing evaporation, and the growth of the pollen-tubes can be observed.

198. Self-Pollination and Cross-Pollination.—In the Broad Bean, as in many other plants, it is found, on making experiments in artificial pollination, that it is better if the pollen comes from a flower on another plant of the same species (*cross-pollination*) than if it comes from the anthers of the same flower or from those of another flower on the same plant. The two latter cases are very similar in their results, and may be both included under the term self-pollination. When cross-pollination occurs, the resulting seeds are generally more numerous or heavier, and give rise to stronger offspring (superior in height, weight, fertility, etc.) than is the case when self-pollination occurs.

In self-pollination there is a mixing of practically similar characters, while in cross-pollination there is a mixing of more or less dissimilar characters, especially when the plants that produce the male and female cells live far apart and under different external conditions. Also, any useful variation is likely to be transmitted and even strengthened when cross-pollination occurs. There is, therefore, an obvious advantage to the species in securing cross-pollination, and we find many adaptations, some of them very remarkable, which favour cross-pollination and hinder self-pollination (Art. 209).

199. How Pollen is Carried.—Pollen-grains have no power of spontaneous movement. When the anthers are above the stigma, self-pollination may occur (if the two are mature at the same time) by pollen simply falling on the stigma, but for cross-pollination the grains must be carried to the stigma of another flower by water, wind, or animals. Water-pollination occurs only in water-plants, and only in a few of these. In this country insects are probably the only animals concerned in carrying pollen from flower to flower, but there are flowers whose pollination is effected by birds (especially humming-birds), bats, and even snails.

200. Mechanism of Broad Bean Flower.—Here cross-pollination is brought about by bees, which may be seen at work on the flowers if you watch plants growing in the open during fine weather. Wind-pollination is out of the question in this case, since the stamens remain enclosed in

the keel. When a bee alights on the flower it stands on the two wing-petals, which bend down under the weight of its body. Since the wings are jointed with the keel, the latter is also pressed down. If you carefully watch the bee at its work, or imitate its action by pulling down the tip of the keel, you will see that when this happens a mass of pollen is brushed out of the keel by the tuft of hairs on the style, and the stigma projects from the keel as well. Some pollen is deposited on the bee's hairy body, which also rubs against the stigma; if the bee has visited another flower previously, some pollen will be left on the stigma. When the bee leaves the flower the keel rises to its former position, and the process may be repeated a few times when other bees visit the flower.

201. Attractions of Broad Bean Flower.—Why does the bee visit this flower? Notice the long tongue (proboscis) which the bee pokes into the lower part of the stamen-trough below the free stamen. It is easy to see this if you pull off the standard and carefully watch the next bee that comes to the flower. What does the bee find here?

Take a newly opened flower and remove the calyx and corolla, then pull apart the stamen-trough and the pistil, and notice the liquid which has collected at the bottom of the trough around the base of the ovary. By tasting, or by the Fehling's solution test, one finds that sugar is present in this liquid—the honey, or *nectar*—which is produced by gland-cells at the base of the stamen-trough.

The bee is guided to the flower, in its search for honey, by the white corolla (easily distinguished among the foliage, and made more conspicuous by the velvety black spot on each wing-petal) and also by the fragrant odour which is emitted by the petals.

The coloured streaks on the standard help to guide the bee to the opening below the free stamen; but its removal does not prevent a bee from finding this opening, as can easily be seen by making the experiment.

Since the honey can only be reached when the keel is pressed down with some force, and is produced at the bottom of the tube formed by the stamen-trough (closed above by the free stamen and the standard), it can only be reached by

an insect with a heavy body and a fairly long tongue. The flower is specially adapted to the visits of bees.*

Sometimes a bee when working at the flowers may be seen to bite through the calyx-tube and insert its tongue through the hole thus made, thus reaching the honey without entering the flower in the "proper" way, *i.e.* from the front. Many other "bee-flowers" (*i.e.* flowers specially adapted for bees' visits) show neat round holes bitten out by the bee in its short cut to the honey, of which it robs the flower without rendering any service in return.

202. Functions of the Calyx.—The calyx has three important uses in the Bean-flower. (1) It protects the inner parts of the young flower. In the bud, the stamens and pistil are enclosed in the keel, the wings are folded over the keel, and the standard over the wings, and the calyx is wrapped over the outside of all. (2) When the flower opens, the corolla expands, pushing aside the calyx-lobes, then the standard curves upwards, and the flower is ready for the visits of bees. The calyx then serves to hold the petals together and prevent their falling apart. (3) The calyx also protects the young fruit to some extent from becoming dried up.

203. The primitive, or simplest, type of **calyx** consists of spirally arranged *sepals*, which arise directly from the receptacle, as small green sessile leaves. The individual sepals may be free (*polysepalous* calyx), or more or less united (*gamosepalous* calyx). However complete the union may be, the number of sepals which take part in the formation of the calyx is usually indicated by the pointed teeth borne on the upper margin of the tube. In the Monkshood the petals are very much reduced, and one of the sepals form a coloured arching hood placed at the back of the flower.

When a calyx is present, it is usually composed of two, three, four, or five sepals. Thus the Poppy has a single pair, the Lesser Celandine a whorl of three, the Violet one of five sepals, while the Wallflower has four sepals in pairs, forming an inner and an outer whorl of two. More rarely the sepals are numerous, and retain their primitive spiral arrangement (Water-lilies, Cactuses).

The calyx commonly serves to protect the flower while it is still young, and hence, when the flower opens, the sepals either fall off (Poppy) or turn back (Dog Rose). Another of its functions, however, is to protect the developing fruit, and hence it often persists until the

* The Broad Bean flowers are also visited by butterflies and moths.

fruit is formed, as in the Bean, Strawberry, and Dead-nettle. A gamosepalous calyx affords not only a more efficient protection to the flower-bud than a polysepalous one, but also gives support and protection to the base of the adult flower and to the developing fruit. Hence the gamosepalous calyx never falls off when the flower is young. In "Winter Cherry" the calyx forms a red bladder round the fruit.

When the flowers and fruits are closely aggregated, they no longer need a protective calyx, which therefore becomes quite small, as in Umbellifers, and when a closely packed mass of flowers is surrounded by a ring of protective bracts, the calyx may either disappear (Daisy) or be represented only by hairs. These hairs in the Dandelion, Thistle, Hawkweed, etc., persist after flowering, and form a *pappus*, which is attached to the ripened fruit and aids in its dispersal by the wind.

The sepals are usually green, but the "petaloid" sepals of Monks-hood, Winter Aconite, Christmas Rose, Larkspur, and Marsh Marigold are brightly coloured, and take on the attractive function of the corolla. In the Wallflower the two outer sepals are slightly pouched at their bases, so that they may retain the nectar secreted by the glandular swellings placed beneath the bases of each of the two shorter stamens.

204. Functions of the Corolla.—We have seen how the standard and the wings help in attracting bees to the flower, and how the wings work with the keel in causing the bee to carry away pollen as well as to bring pollen from other Bean-flowers to the stigma. The keel by enclosing the stamens prevents rain from spoiling or washing away the pollen, and protects it from being shaken out of the flower by wind; it also prevents the nectar from being reached by useless insects, from loss by evaporation, and from being diluted or washed out by rain. The protection of the nectar is made still more complete by its being formed inside the stamen-trough.

205. The primitive Corolla consists of a spiral of free petals. In most plants this has been changed into a single whorl (Foxglove, Geranium) or, more rarely, a double whorl of petals (Poppy). The corolla protects the stamens and carpels at the most critical period of their existence, and this is especially the case when the petals have grown together to form a tube enclosing the essential organs. The corolla-tube often serves as a receptacle for honey, while the coloured portion attracts the visits of insects. As soon as fertilisation has occurred, the seeds begin to develop, and an attractive corolla being no longer needed, it is usually rapidly shed. The withered corolla may, however, persist round the fruit (*e.g.* Heaths, Plantains, Clover).

When the corolla is polypetalous, the individual petals often consist of a narrow stalk or *claw*, and an upper broader portion, the blade or *limb*. The petals of the Pink have a scaly outgrowth (ligule)

at the junction of the claw and limb, and in *Narcissus* there is a circular cup, or *corona*.

The corolla is said to be *regular* when all its parts are similar, *irregular* when they differ in shape from one another, and the same terms apply whether it is poly- or gamopetalous. In Christmas Rose and Winter Aconite the petals are represented by hollow nectaries, and the sepals form the showy attractive portion of the flower. The nectaries are represented in the Buttercup by tiny pockets placed behind a scale at the base of the inner surface of each petal. Hence the nectaries of the Christmas Rose are probably modified petals, as are undoubtedly the two posterior ones of the Monkshood.

206. The **Andrecium** is the collective term applied to the whole of the stamens present in any single flower. Each stamen usually consists of two parts, a stalk or filament, and a head or anther. There may be no filament, so that the anther is sessile, or the anther may not develope, when what remains is known as a *staminode* or sterile stamen. The anther is usually divided into two halves or lobes, in each of which are a couple of longitudinal compartments, filled, when ripe, with pollen grains. When the anther splits open, or *dehisces*, the partition between the paired pollen sacs of each lobe breaks down to a greater or less extent, so that each lobe appears to have only a single cavity (Fig. 45). In a few cases the stamen splits into two when quite young, so that each piece has only two pollen sacs (Hazel, Hornbeam).

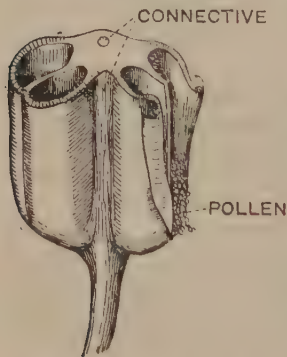


Fig. 45.—An Anther with the top cut off.

The right anther lobe is represented as being dehiscent.

The prolongation of the filament between the two lobes of the anther is termed the *connective*. When the lobes are close together, this is narrow; but in Labiates and some other plants the connective is elongated laterally, and the anther lobes are widely separated. Special appendages

are occasionally developed from the connective; each anther of the Violet has a membranous orange-coloured outgrowth at its apex, and in addition each of the two anterior stamens has an elongated process extending downwards into the spur of the anterior petal. The tip of this process is glandular, and secretes nectar into the spur.

As a general rule the different stamens of a flower are alike in shape, size, and in length of filament. Two of the stamens of the Wallflower, however, are shorter than the other four (*tetradynamous*), while the Dead-nettle has two long and two short stamens (*didynamous*).

The fully grown anther breaks open and allows the pollen to escape. It usually happens that the wall of each lobe splits longitudinally along

the dividing line between its two compartments, but in many Labiates the anther opens transversely. In Potato, Rhododendron, Milkwort, etc., small pores are formed at the top of the anther. In the Barberry the whole side of each anther-lobe bends upwards; in the Laurel small doors or valves open at the sides of the anther.

207. The Gynecium or Pistil is the collective term applied to the carpels present in a flower. In its simplest form the pistil consists of a single carpel, as in the Bean. Such a carpel corresponds to a leaf bearing ovules on its margins (Fig. 46), a condition in which the carpels of the Gymnospermous plant *Cycas* remain to the present day. We might suppose that as the higher flowering plants developed, the two halves of the carpellary leaf became folded longitudinally, and that their margins grew together along a line known as the ventral suture, which bears a double row of ovules derived from the two margins of the leaf.



Fig. 46.—Carpellary Leaf with Marginal Ovules.

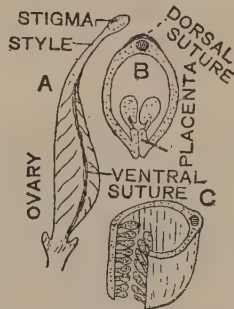


Fig. 47.—The Monocarpellary Pistil.

A, Entire; B, Transverse section of Ovary; C, Will indicate method of folding.

The purpose of this change is immediately obvious, for the young ovules are now protected within a hollow chamber known as the *ovary* (Fig. 47), which is formed from the swollen basal portion of the carpel. The apical portion of the latter forms a slender prolongation of greater or less length, the *style*, which usually contains a central canal communicating with the cavity of the ovary, but may be composed of loose, solid tissue with no definite central cavity. The *stigma*, or apical portion of the style, is usually swollen and covered with hairs (stigmatic papillae). The stigma forms the receptive surface for the pollen. The dorsal suture of the carpel corresponds to the midrib of a leaf;

the cushion of tissue along the ventral suture, from which the ovules arise, is known as the *placenta*.*

The flower of Buttercup or Rose contains several free simple carpels, and the pistil is therefore termed *apocarpous*. When several carpels are present in a flower, they are often united to form a compound or *syncarpous* pistil. The union may be confined to the base of the ovary (some Saxifrages), or may include the entire ovary (Campion), or only the stigmas may be free (Foxglove), or all three may be completely united together (Primrose). A syncarpous ovary may be divided into a number of chambers, each corresponding to the cavity of one carpel. Thus the Tulip has three carpels, and the ovary is divided into three chambers, each containing a double row of ovules.

The ovary of the Violet has a single chamber only, although it is composed of three carpels, as is indicated by the presence of three

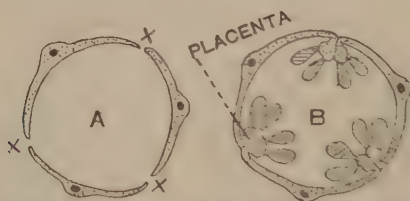


Fig. 48.—Formation of Unilocular Ovary from three Carpellary Leaves by Fusion at X.

groups of ovules arranged in longitudinal rows upon its wall. When, as in this case, the ovules are attached to the wall of a compound ovary, the placentation, or arrangement of the placentas, is said to be *parietal* (Fig. 48); but when the ovules arise from the longitudinal axis in the centre of the ovary, the placentation is said to be *axile* (Fig. 49), e.g. Bluebell, Tulip. It will be noticed that when the placentation is axile, the ovules in each loculus are derived from the margins of the carpellary leaf that forms this chamber, whereas in the case of parietal placentation each group of ovules is derived from the margins of two adjacent carpellary leaves, half from each. In Chickweed, Stitchwort, Campions, Primrose, etc., the central axis of the ovary does not reach the roof of the latter, so that the ovules appear to arise from a mound in the centre of the ovary. This type of placentation is said to be *free-central*, and it is probably a modified form of axile placentation, in which the dividing septa do not develop; this is probably not a primitive condition, but a secondary adaptation, the attachment being such that the ovule is more readily provided with food.

* In the Water-lily, Flowering Rush, and a few other plants, the ovules are scattered all over the inner surface of the carpels.

The only safe way of determining the number of carpels in a syncarpous gynoecium is by studying its development, and noting how many leaf-rudiments fuse to form it. Adult flowers, however, often afford evidence of value to beginners. Thus the number of chambers in an ovary usually corresponds, if there are more than one, to the number of carpels of which it is composed. In Labiates and Borages, however, each compartment of the bicarpellary gynoecium is divided into two, so that there are four loculi, but only two carpels. The ripe ovary of the Flax becomes similarly divided into ten chambers instead of the five present at first.

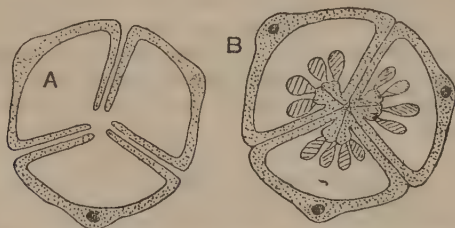


Fig. 49.—Formation of Trilocular Ovary, B; from three Carpellary Leaves, A.

Again, in unilocular ovaries with parietal placentation, each placenta usually corresponds to a single carpel, although in the case of the Water-lily the inner surfaces of the carpellary compartments of the ovary are studded with ovules. The number of styles or stigmas often corresponds to the number of component carpels, and the ripe fruit frequently splits into as many pieces as there are carpels.

In White Water-lily the numerous petals pass by gradual transitions into the more centrally placed stamens, all being spirally arranged on the receptacle; in double Roses the stamens, in double Buttercups both stamens and carpels, become petal-like; in White Clover the carpel sometimes remains open and produces green leaves on its edges; in Green Roses, double Cherry, etc., the carpels grow into green leaves.

208. Inflorescences.—Flowers may either be solitary or may occur in clusters. In the latter case they are usually subtended by special leaves termed bracts. Solitary flowers may be terminal, as in Tulip and Daffodil, or may arise in the axils of ordinary leaves, as in the Scarlet Pimpernel and Money-wort. Such flowers may in some cases (*e.g.* Violets and Pansies, where the stalk bears two small bracts) be regarded as reduced inflorescences, in which the main axis remains unbranched, and only one flower develops. The branching of an inflorescence may be either cymose or racemose. In

racemose inflorescences the main axis is stouter and longer than the lateral ones, whereas in the cymose type the lateral axes branch more than does the main axis beyond them. The growth of the main axis is in this case strictly limited, and it bears usually one or two lateral axes, instead of the numerous ones which characterise most racemes.

The order of flowering usually follows the order of development, and hence the flowering in racemes is generally centripetal, whereas that of cymes is on the whole centrifugal. That is, in the first case the youngest flowers are nearest the apex (in a long inflorescence) or the centre (in a flat- or round-topped inflorescence), while in the second case the youngest flowers are nearest the base or the outside of the inflorescence.

The simplest type of **raceme** consists of an elongated axis or peduncle which bears stalked flowers (stalks about equal in length), *e.g.* Foxglove, Hyacinth. If the branches of the parent axis branch again so that each secondary axis bears several blossoms instead of one, we have what is known as the compound raceme or **panicle**. This is the most primitive type of inflorescence, for it is really the modified upper region of the plant, whereas the simple raceme is more highly differentiated and has become simple by reduction. Many terms have been applied to racemose inflorescences which look peculiar at first sight, but on further observation are seen to differ in small details only. The more important of these are (1) **Corymb**: axis elongated, flower-stalks unequal in length, bringing the flowers to about the same level (Candytuft); (2) **Spike**: axis elongated, flowers sessile (Plantain, Orchids); (3) **Catkin**: a spike bearing unisexual flowers of one kind (Willow, Hazel); (4) **Spadix**: a spike with fleshy axis, usually bearing unisexual flowers, enclosed by a large bract, the **spathe** (Arum); (5) **Simple umbel**: axis shortened, flowers stalked (Cowslip); (6) **Capitulum**: axis shortened and expanded, flowers sessile (Composites).

Cymose inflorescences are those in which the axis ends in a flower after bearing one, two, or more daughter-axes, each of which may repeat the process. The daughter-axes may come off singly (**uniparous cyme**)—*e.g.* Forget-me-not and other Borages, Sundew; or in opposite pairs (**biparous cyme**)—*e.g.* Stitchwort and Campion Family, Red and Yellow Gentians; or in whorls of three or more (**multiparous cyme**)—*e.g.* Elder.

Examine and sketch the various kinds of **flat-topped inflorescences** met with, noting that plants with inflorescences of this kind are found in many different Orders—*e.g.* Cruciferae (Candytuft, etc.), Rosaceae (Cherry, Rowan, Meadowsweet, Hawthorn, etc.), Leguminosae (Clovers, Lotus, etc.), Umbellifers, Ivy, Dogwood, Elder, Valerians, Dipsaceae, Sheep's-bit, Compositae, etc.

It seems probable that all cymose inflorescences have been derived from racemose ones by a shortening of the main axis and a delay in the development of the lateral branches, to which the main power of growth is at the same time transferred. The cymose inflorescence is certainly an advance upon the racemose type, for in the former new flowers continually appear on the exposed surface of the inflorescence, while the fruits ripen securely buried among the older parts of the mass of branches. The tendency in racemes, on the other hand, is to simultaneous flowering, such as is exhibited more or less perfectly by so many umbels and capitula and especially by corymbs. In such cases there is an ever-present danger that the short period of flowering may occur at a time when the conditions are not suitable for the production of fertile seed. Racemes such as those of the Wallflower, in which the lower flowers may open months before the apex of the raceme ceases flowering, do not incur this danger, but the exposed position of the young succulent fruits is an obvious disadvantage here and in other Crucifers also. Moreover, if the growing point of a young raceme is destroyed, the power of producing flowers may be temporarily lost, whereas the destruction of the apex of a cyme involves the loss of a single flower only, and the lateral axes continue their growth with even greater vigour than before.

Compound inflorescences are those in which the lateral branches are again branched in the same way as the parent axis. The commonest kinds are (1) **Panicle** (raceme of racemes or spikes), common in Grasses; (2) **Compound spike** (a spike of spikes), in some Grasses, e.g. Wheat; (3) **Compound umbel** (umbel of umbels), much commoner than the simple umbel (most Umbelliferae).

In many cases **mixed inflorescences** occur—as, for example, racemes of spikes, capitulums, or cymes, spikes of capitulums, etc. It must, however, be borne in mind that there are only three main types of inflorescence, and these are (1) the raceme, with its reduction derivatives grouped around the generalised panicle type; (2) the biparous cyme; (3) the uniparous cyme. “Mixed” inflorescences arise owing to the fact that reduction or alteration has unequally affected the different parts of the primitive paniced inflorescence. The inflorescence of the garden Geranium (*Pelargonium*) and of many Narcissi resembles an umbel, but the flowers in the apparent umbel are really arranged in little cymose clusters, so that the whole inflorescence has been termed an umbellate cymose head.

209. Contrivances and Conditions favouring Cross-Pollination.—There are in flowers many forms, conditions, and mechanisms, the significance of which becomes clear only on the view that cross-fertilisation is advantageous, and that the flowers have become adapted to it. Such mechanisms, etc., either entirely prevent self-pollination, or tend to do so, and are distinct adaptations for cross-pollination.

To commence with, in many plants cross-pollination is absolutely necessary if seed is to be produced, owing to the flowers being unisexual. We have this condition in its extreme form where the staminate and pistillate flowers are on different plants (*e.g.* Willow). Some plants are self-sterile, *i.e.* the flower cannot be fertilised by its own pollen; this occurs in some species of Passion-flower, of Lobelia, of Abutilon, etc.

Dichogamy is a condition in which, though the flowers are hermaphrodite, the anthers and stigmas come to maturity at different times, and which, when completely developed, entirely prevents self-pollination. There are two kinds of dichogamy: (*a*) **protandry**, where the anthers ripen first: here the pollen grains are transferred to an older flower; (*b*) **protogyny**, where the stigma ripens first: here the pollen grains are transferred to a younger flower. Protandrous flowers are much more common than protogynous. Examples of the former are found in Composites, Labiates, Harebells, Ivy, Umbellifers, Willow-herbs, etc.; of the latter in some Grasses, Plantains, Woodrush, Figwort, Hawthorn, etc. Wind-pollinated flowers are more often protogynous than protandrous, but many are unisexual.

Wind-pollinated and insect-pollinated flowers have each special characters of their own, so that as a rule we can distinguish them at a glance. In wind-pollinated flowers the pollen is produced in great abundance, as much of it must be wasted; the flowers are small and inconspicuous; there is no honey or perfume; and frequently the stigmas are branched and feathery, to catch the pollen grains.

The greatest variety, however, is shown in insect-pollinated flowers; there is no difficulty in recognising these as being the most highly specialised. As a rule they have large, conspicuous, brightly coloured corollas, or are arranged in conspicuous inflorescences; they usually secrete honey and give out perfume. Pollen is not usually produced in great abundance, as the provision for its transference is more perfect. The bright corollas, the perfume and honey, serve to attract insects. In return for the service rendered by insects the flowers sacrifice part of their nutritive substance in providing food to the insects (honey and pollen), and make a further sacrifice of energy in developing certain structures (corollas) which will attract the insects. By instinct insects

associate these attractive structures with the presence of a supply of food-material.

In many cases the corolla is so modified that the insect must alight on the flower or enter it in a special way (*e.g.* Labiates, Papilionaceae); the same result may be attained by the secretion of nectar into special receptacles or spurs (*e.g.* Violet); or the insect, on entering a flower, pushes against special processes or outgrowths which move the stamens and bring the anthers in contact with its body (Sage); or the stamens may be jerked, and the pollen scattered over the insect's body (Barberry, *Kalmia*).*

The general result of all these devices is that the insect receives the pollen on a special part of its body, and when it enters another flower the pollen is deposited on the stigma. In many protandrous flowers this is secured by the style bending over so that the stigma is in the position formerly occupied by the stamens.

A very special, but at the same time very simple, arrangement for making the best use of the insects is the condition known as **heterostyly**. It is seen in the Primrose. Here there are two types of flower borne on different plants. One kind has long stamens (with anthers in the throat of the corolla tube) and a short style; the other has a long style and short stamens; thus in the two types the positions of anthers and stigma are simply reversed. Evidently pollination will be most readily effected by transference between these two forms, and not between two flowers of the same form; and experiment has proved that the best seed is produced when this is the case.† (See Ch. XII.)

210. Special Arrangements for Self-Pollination.—Many annual plants cannot afford to undertake the risks and sacrifices attendant on cross-pollination, and are commonly self-pollinated (*e.g.* Groundsel, Chickweed). They have small flowers, often without honey or smell, and are either

* For details of the wonderful mechanisms of many insect-pollinated flowers see (besides this book) the author's *Plant Biology*, also Willis' *Flowering Plants and Ferns*, Knuth's *Handbook of Flower Pollination*, and Church's *Types of Floral Mechanism* (the first volume of which has just been published).

† Other plants with heterostyled flowers are Purple Loosestrife (*Lythrum*), Flax (*Linum*), Lungwort, Bog-bean (*Menyanthes*).

homogamous—that is, their anthers and stigmas mature at the same time—or so slightly dichogamous that self-pollination is secure. Even in flowers evidently adapted for cross-pollination there is commonly the possibility of self-pollination as a last resort. Many of them are distinctly dichogamous, but not completely so, there being usually a short period during which self-pollination becomes possible. To effect this there are sometimes special contrivances, such as the curling back of the stigmas to reach the pollen (*e.g.* *Nigella*, *Composites*, *Campanulaceae*).

A very special adaptation for self-pollination is the production of **cleistogamic flowers**. These are closed flowers produced late in the year by certain plants which had previously produced ordinary flowers—*e.g.* Violets, Wood Sorrel, Henbit Dead-nettle (*Lamium amplexicaule*), etc. (See Arts. 266, 268.) In our study of flower-mechanisms we are too apt to forget that self-pollination occurs regularly in most flowers where it is not precluded by dioecism, complete dichogamy, or self-sterility, that it is rarely *much* inferior to cross-pollination in its results, and that it is always better than *no* pollination.

211. Insects that visit Flowers.—The chief flower-visiting insects are beetles (Coleoptera), flies (Diptera), bees and wasps (Hymenoptera), butterflies and moths (Lepidoptera). For our purposes, the chief differences between these insects are the size of the body, the length of the tongue or proboscis, the time of year at which each kind is most plentiful, and their habits—*e.g.* whether they collect pollen or honey or both, whether they fly by day or in the evening.

By carefully studying the structure of a flower, and noting such points as the time of flowering, the order in which the anthers and stigmas mature, the relative positions of anthers and stigmas in the open flower and any changes in position that may occur, we can often tell what kind of insect is capable of effecting cross-pollination, and whether or not self-pollination is possible. We shall deal later with the characters of flowers which are mainly or entirely pollinated by the wind, and which lack the conspicuous colouring, scent, and nectar which are characteristic of insect-pollinated flowers (though not necessarily *all* present in the same flower).

There is only one way in which to study this fascinating subject—by going out and patiently watching the various insects which visit flowers. If you can get to know the names of the insects, do so; in any case it is usually easy to tell whether it is a butterfly or moth (four wings covered with scales, proboscis often long and coiled up, feelers or antennae with club-like ends in most butterflies, tapering and feathery in most moths), a bee or wasp (wings membranous, body usually banded with yellow and black; ovipositor at hinder end of female's body, used also as a sting), a fly (two clear wings with no scales or hairs and few veins—mostly longitudinal), or a beetle (front wings form two hard cases—elytra—covering the two soft hinder flying-wings, mouth-parts adapted for biting only). However, there are many books on these classes of insects, some of which should be consulted; note especially the size of the insects, their habits and mode of life, and their mouth-parts.

It is interesting, if a microscope is available, to examine pollen-grains of known flowers, sketch them, and keep preparations (mounted in glycerine jelly) for reference, and then to catch insects and examine any pollen-grains that may be on their bodies.

212. Flowers adapted for Short-tongued Insects.—Most flies and beetles have very short tongues, usually less

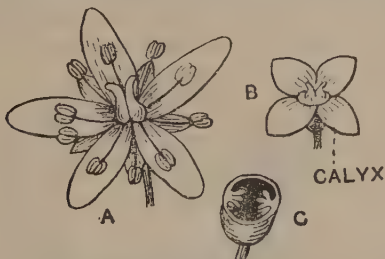


Fig. 50.—A, Flower of a Saxifrage; B, Flower; C, Ovary of *Chrysosplenium* (Golden Saxifrage).

than 3 mm. long (about one-eighth inch), and are only able to lick honey which is freely exposed on the surface, as in Ivy, Umbellifers, Dogwood (*Cornus*), Bedstraw, Goosegrass, Golden Saxifrage (Fig. 50, B, c), or in flowers with a very short tube, *e.g.* Moschatel, Enchanter's Nightshade (Fig. 51), or in various shallow open flowers, *e.g.* Saxifrages (Fig. 50 A), Stonecrop (Fig. 52). They can of course visit any shallow flowers, and at least get pollen from honeyless "pollen-flowers," *e.g.* Wood Anemone, Clematis, Poppy, Dog Rose,

Rock Rose, St. John's Wort. Some flowers show remarkable adaptations for pollination by flies, which are, as a rule, much lower in intelligence than the other classes of flower-visiting insects.

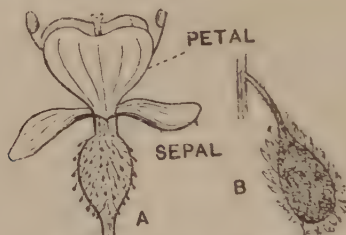


Fig. 51.—A, Flower; B, Fruit of Enchanter's Nightshade.

One of the commonest beetles seen visiting flowers is a small bronze-black one called *Meligethes*, but very few beetles have tongues over 3 mm. Most of the larger and longer-tongued flies (*e.g.* the Tabanids—Gad-flies, "Cleggs," Horse-flies) do not visit flowers, those just mentioned being blood-suckers, but some (with tongues sometimes as long as 12 mm.) are regular flower-visitors. These belong chiefly to two families—Hover-flies (Syrphids) and Bee-flies (Bombylids). The former

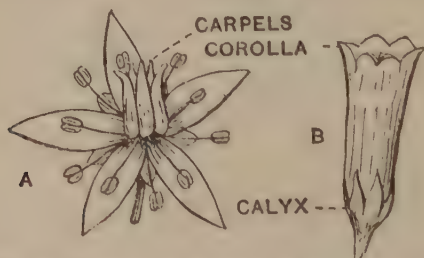


Fig. 52.—Flowers of A, Stonecrop; B, Wall Pennywort.

(*Eristalis*, *Syrphus*, *Rhingia*, etc.) often resemble bees and wasps in having a banded body, and many flowers are adapted for their visits, *e.g.* Speedwell, in which the two stamens form an alighting-place for the fly. The Bombylids also visit flowers, and some are nearly as clever as the bees they resemble at finding concealed honey with their long tongues; of the few British forms, *Bombylius* (hairy body, humped thorax, slender legs) is of great importance in the pollination of spring flowers, *e.g.* Primrose (Art. 276).

Among the smaller flies (tongues less than 3 mm. long) several visit flowers, e.g. *Lucilia* (small blue-bottle), *Anthomyia*, Dung-flies, Midges, Thrips; some of these feed on decaying matter, and some flowers appear to be specially adapted for their visits, having a peculiar odour, e.g. *Arum*, Hawthorn, Moschatel.

213. The Cuckoo-pint.—Examine the peculiar “flowers” of the Cuckoo-pint (*Arum*), so common in our hedgerows, where it blooms in April and May (Fig. 53). The whole “flower” is enclosed in a large green and purple leaf (the *spathe*). The upper portion of the spathe opens, exposing the bright purple club-shaped upper part of the spadix, while the lower bulbous portion remains closed except at the top, where it contracts to form a narrow throat. Cut open the lower part, and you see that the spadix is continued downwards, forming an axis, round which are situated two clusters of small flowers. The upper cluster is a dense mass of male flowers, each consisting of a single stamen; and the lower is a similar mass of female flowers, each consisting of a single carpel. Above each cluster are some abortive flowers that are reduced to hair-like structures, those above the stamens being longer, directed downwards, and lying in the contracted portion of the spathe.

If the flower under examination has recently opened, we find that the female flowers only are mature, but if it is one that has been open for some time, the female flowers are beginning to develop into fruits, and at the same time secrete a sweet fluid, while the male flowers are shedding their pollen. Thus the female flowers are not pollinated by the agency of the male flowers above them; how then are they pollinated?

On opening the lower part of the spathe we always find within it a number of little flies (“Midges”) which have been assisted in finding their present abode by the conspicuous nature of the spathe and spadix. All these flies are more or less dusted with pollen collected either here or from flowers previously visited. When the flies visit an *arum* during its first or female stage, they find no food, and crawl about in their attempts to escape; but they are securely entrapped by the hairs at the neck of the spathe, which hairs, pointing downwards, allow easy access to the interior, but effectually prevent escape. However, in their movements the flies rub their bodies over the sticky stigmas, which are thus pollinated by the grains previously obtained in other *Arums*.

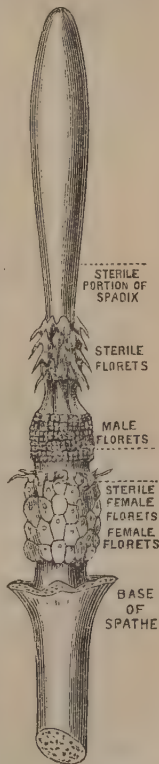


Fig. 53.—Spadix of *Arum*.

Spathe removed to show the Flowers.

The fertilised ovaries now begin to develop into fruits, while the anthers open, shedding abundance of pollen grains that cover the bodies of the imprisoned flies. Then the hairs wither, setting free the flies after the work of pollination has been effected, and after they have become covered with pollen to prepare them for a repetition of the process in other flowers visited.

214. Grass of Parnassus.—In this plant, which grows in boggy places, flowering in late summer, the large solitary white or yellow flower (Fig. 54) has five outer sterile stamens (staminodes) which bear



Fig. 54.—Vertical Section of Flower of *Parnassia palustris*.

nectaries on their inner faces, and end in a series of stalked knobs; within, and alternating with, these are five fertile stamens. The knobs are shiny and resemble drops of honey, but are quite dry and hard; they attract and deceive flies, which may sometimes be seen licking them. The fertile stamens as they mature bend up over the pistil, one by one in succession, and then the anthers open on the outer side, shedding the pollen on the flies, which are the flower's chief visitors; after all five anthers have opened, the four stigmas spread out.

215. Flowers with partially Concealed Honey.—Many flowers have arrangements for concealing the honey from the shortest tongued insects, so that the visiting insects must have tongues at least about 4 mm. in length to reach it. The honey may be slightly concealed by the stamens—*e.g.* Buttercup, Stitchwort; by the erect, stiff sepals in the smaller Crucifers; by the formation of a shallow receptacle-cup in many Rosaceae—*e.g.* Strawberry, Cinquefoil; or by a short corolla-tube—*e.g.* the shorter-tubed Composites and Labiates, All-Heal (*Valeriana*), Guelder Rose, Speedwell. Such flowers are visited by the longer-tongued beetles and flies, as well as by insects of higher type.

216. Flowers with fully Concealed Honey.—This type of flower differs only in degree from the last. Here the honey is out of the reach of the short-tongued insects, and can only be obtained by those having tongues about 6 mm. long, including the longest-tongued flies (chiefly the Hover-flies and Bee-flies) and the shorter-tongued bees—*e.g.* burrowing bees (*Andrena*, tongue 2 or 3 mm.), hive-bees (*Apis*, tongue 5 or 6 mm.), and wasps.

The concealment of the honey is effected by a further deepening of the flower, due to formation of a receptacle-tube, or to the sepals or petals (or both) growing out vertically from the receptacle (instead of spreading as in shallow flowers), and in many cases being joined below to a tube—*i.e.* being gamosepalous or gamopetalous.

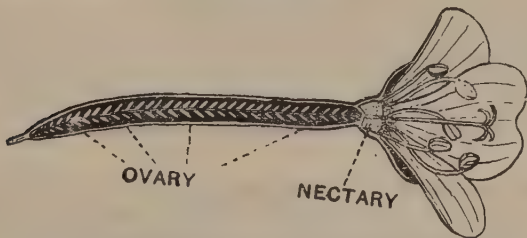


Fig. 55.—Vertical Section of Species of *Epilobium* (Willow-herb).

Examples of these medium-tubed flowers are seen in Black-berry, Currants, Gooseberry, Pasque Flower, Willow-herb (Fig. 55), Geranium, Mint (compare these to see how the tube is formed in each case, and try to find other examples). Some flowers seem to be chiefly visited by wasps, *e.g.* Figwort (*Scrophularia*), Snowberry, *Epipactis*, Cotoneaster.

217. Long-tubed Flowers.—When the flower-tube becomes longer, all these shorter-tongued insects are more or less completely excluded, and the flower is adapted for, and chiefly visited by, the larger bees (especially the humble-bees), butterflies, and moths. Many flowers belonging to the Lily, Daffodil, and Iris families of Monocotyledons come under this type. In most long-tubed flowers the honey is found only in the lower part of the tube, but in Crocus it fills the space between the style and the long flower-tube, and

is therefore easily reached by bees and butterflies; this is also the case in the Dandelion (Art. 280).

Flowers like those of Papilionaceae, Snapdragon, and Toad-flax can only be opened by large bees, and only the longest-tongued bees can reach the honey in such flowers as Monkshood and Larkspur. The humble-bees have longer tongues (about 10 mm. in *Bombus terrestris*, 20 mm. in *B. hortorum* and in *Anthophora*) than hive-bees. Moreover, the humble- and hive-bees have the most perfect mechanism (the "pollen-baskets" on the hind-legs) for collecting pollen to mix with honey and feed their brood. Humble-bees are particularly skilful in finding the way to well-concealed honey. In this connection compare Red Clover and White Dead-nettle (humble-bees) with White Clover and Red Dead-nettle (smaller bees). See Arts. 267 and 276.

Blue, purple, and red colours are often associated with flowers visited by bees (especially blue and purple) and butterflies (especially red), while flowers visited by other insects are usually white, yellow, or variegated; but there are far too many exceptions to allow of a general rule.

218. Butterfly- and Moth-Flowers.—When the flower-tube (or at any rate the level of the honey) is more than about 12 mm. (about half an inch) deep, the honey is beyond the reach of bees, though they may visit the flower for pollen or the humble-bee may bite through the tube and thus rob the flower of its honey. Good examples of butterfly-flowers are seen in Red Campion and Ragged Robin, but butterflies also visit many flowers adapted for bees, *most* British butterflies and moths having tongues of about the same length as, or a little longer than, those of bees (about 15 mm.).

Some moths, however, have far longer tongues (30 mm. in a few British species),* which are (as in butterflies) carried coiled up in a spiral under the head when flying. These moths can reach honey even when it is at the bottom of a very long tube, as in the Honeysuckle (Fig. 56), which is visited chiefly by the night-flying Privet Hawk-moth, and

* In some foreign moths the proboscis reaches the astonishing length of 300 mm. (about 12 inches). See the articles in Willis' *Flowering Plants and Ferns* on *Angraecum*, *Yucca*, *Lilium*, *Lonicera*.

the White Convolvulus, which is said to be pollinated by another species of Hawk-moth (*Sphinx convolvuli*, tongue 80 mm. long), and to set seed very seldom in England owing

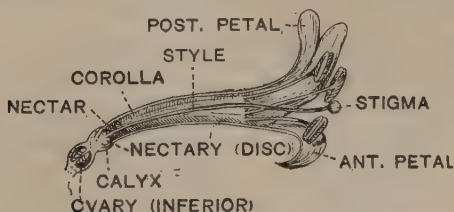


Fig. 56.—Longitudinal Section of Flower of Honeysuckle.

to the rarity of this moth. Other flowers pollinated by night-flying moths are the White Campion (*Lychnis vespertina*), Evening Primrose (Fig. 57), Tobacco Plant, Privet, Bladder Campion. Moth-pollinated flowers are white or pale-

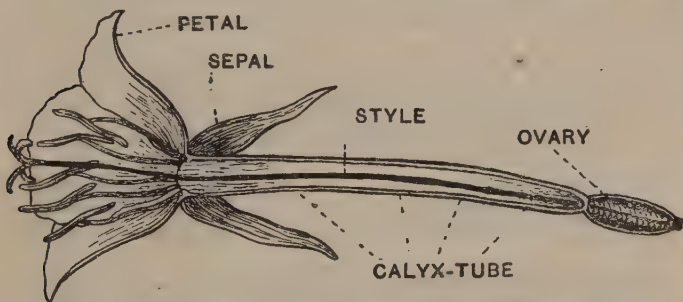


Fig. 57.—Vertical Section of Flower of Evening Primrose.

coloured, sweetly scented, and open in the evening, usually remaining closed and almost scentless during the day.

219. The Flower-Tube.—It is interesting to compare the various ways in which the flower becomes tubular in form, so as to protect the ovary, to conceal the honey, to shelter the pollen from rain, to exclude short-tongued insects, etc. The study of development shows that, starting from the simple “hypogynous” condition, the formation of a “perigynous” or “epigynous” flower, of a “gamophyllous” perianth, of a “gamosepalous” calyx, of a “gamopetalous” corolla, of “epipetalous” stamens, etc., in short, all the cases of “cohesion” and “adhesion” are due to the growth of the receptacle during the flower’s

development, and that all these conditions in the mature flower are due to differences in the extent of this growth. It is important to remember this, as the various terms in current use tend to obscure the facts of development, and even to imply that actual "fusion" occurs after the various flower-parts have been developed.

220. Protection against Rain.—The flowers already mentioned show examples of the various ways in which the pollen may be protected against rain. Pollen-grains, like seeds, are much less resistant to extremes of temperature and to drying when once they have been moistened and have begun in consequence to germinate. In some flowers, especially those whose pollen is exposed to rain when the flower opens, the pollen grains are not readily wetted, having a covering of wax or of spines, etc. In most cases, however, the grains lose their power to germinate if wetted and then allowed to dry.

Many flowers protect the pollen by their drooping position, *e.g.* Heaths, Bluebell, Lily of the Valley, Solomon's Seal; in some cases the stalk droops at night or in bad weather, *e.g.* Wood Sorrel; or the flower closes up under similar conditions, *e.g.* Tulip, Crocus, Lesser Celandine, Scarlet Pimpernel (in which self-pollination often occurs in the closed-up flower, by the stamens touching the stigma), and the same kind of closing is effected in the flower-heads of many Composites by the movements of the flowers and bracts.* In Iris the large petaloid stigmas cover the stamens, while in Orchis (Art. 286) the single stamen is covered by a hood formed by one of the sepals and two of the petals. Find other examples.

221. Wind-Pollinated Flowers.—Many flowers which contain no honey are visited for pollen by insects, attracted by the colours or scents of these "pollen-flowers." Several examples have been mentioned. This leads to the consideration of flowers which have neither honey, scent, nor conspicuous colours, and which are seldom or never visited by insects. Such flowers are chiefly pollinated by the wind.†

* See the notes and questions on Spring Flowers in Art. 287.

† In a few water-plants the pollen is carried by water, and pollination occurs at or below the surface, but this is rare; most aquatic plants raise their flowers well out of the water, and are pollinated by wind (*e.g.* Pondweed) or by insects (*e.g.* Water Crowfoot, Water Lilies).

222. Comparison of Willow and Poplar (Chap. XVII).—Examine and compare the flowers of Willow and of Poplar, which are very closely allied plants. In both cases the male and female flowers are on separate plants, and are carried on catkins, each catkin consisting of an axis bearing numerous flowers and each flower standing in the axil of a bract. In Willows the male catkins are bright yellow, the female ones green, when the flowers open. Each male flower consists of two (in some species more) stamens, with a honey-gland at their base; the female flower of a pistil with two stigma-lobes (each often forked at the end), ovary one-chambered with numerous ovules on two parietal placentas, and a honey-gland. The flowers are largely visited by bees seeking for honey and pollen among the scanty spring flowers.

In Poplars each male flower has a larger number of stamens (twenty to thirty), surrounded at the base by a cup-like outgrowth (“perianth”), and the female flower of a pistil (similar in structure to that of Willows) with branched stigmas forming a tuft; in neither case is there a honey-gland. The Poplars are wind-pollinated; their flowers have no honey to attract insects. More pollen is produced than in Willows, and the stigmas are more branched, exposing a larger surface; the catkins of Poplars hang down loosely and swing in the wind, and are longer than those of Willows, which usually stand out stiffly from the stem. Moreover, Poplars flower before the leaves appear, and their flowering is generally over by April, when most Willows are beginning to flower; many Willows flower at the same time that the leaves expand.

223. Fagales (see Chapter XVIII).—Many forest-trees bear their flowers (or at least the male flowers) in catkins, or in clusters resembling catkins, but have the male and female flowers on the same plant. In Birch, Alder, and Hazel the male catkins hang down, so that the stamens are covered by the scales (bracts) to which they are attached (as in Poplar), and thus protected from rain. The female catkins are smaller, with stigmas projecting beyond the scales. In Hazel and Alder the catkins are formed from special buds, and are nearly mature in the autumn, ready to open early in spring, before the leaves. In Birch the female catkins are formed in the ordinary buds, and appear along with the leaves. This is also the case with both male and female flowers in Beech and Oak, in which the male flowers have a cup-like “calyx”; in Beech the male flowers are in a cluster at the end of a long drooping stalk, in Oak they are scattered along a similar stalk.

224. Other Wind-Pollinated Flowers.—Plants with wind-pollinated flowers occur in some families which are chiefly insect-pollinated—*e.g.* Meadow-rue (*Thalictrum*) in Ranunculaceae, Salad Burnet (*Poterium*) in Rosaceae (Art. 265). Compare their flowers with those of allied plants in the same family. Examine also the following wind-pollinated flowers:—

Pine, Larch, Yew (Chap. XX).—In these plants the stamens and carpels are on special branches (cones), the pollen is produced in enormous abundance, and the ovules are exposed, so that the pollen-grains reach the micropyle directly.

Stinging-Nettles.—Flowers small and green, male and female either on separate plants or on the same plant; in the male flower the stamens are at first folded inwards and downwards, but on warm, dry days they spring up violently and scatter the pollen in a cloud. Cut

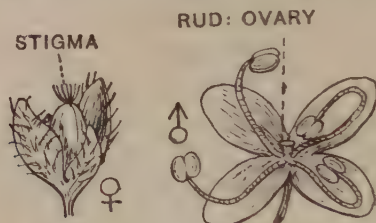


Fig. 58.—Male and Female Flowers of Nettle.

off a branch bearing male flowers, and observe this on touching the coiled-up stamens or warming the flowers. Female flower with a tufted stigma (Fig. 58).

Dog's Mercury.—Flowers small, green, dioecious; stamens numerous; two large stigmas (Fig. 59).



Fig. 59.—Male and Female Flowers of Dog's Mercury.

Plantain.—Flowers in a spike, markedly protogynous; when the stamens of the lower (older) flowers hang out, after the withering of the stigmas, the stamens of the upper (younger) flowers are still in the bottom of the corolla-tube, and the stigmas projecting outwards and ready for pollination (Fig. 60). Some species have coloured anthers, and are slightly scented; these are sometimes visited by insects for pollen.

Other wind-pollinated flowers which you should examine are those of Hop (Fig. 61), Sedges, Rushes, Docks, Sheep's Sorrel, Crowberry (Art. 272), Walnut, Oriental Plane, Ash (Art. 311), Elm (Art. 306), Grasses (Chap. XVI.).

225. Characters of Wind-Pollinated Flowers.—In wind-pollination it is obvious that the chances of a pollen-grain striking a stigma are very small, and that the plant

must therefore produce a much larger amount of pollen than is the case in insect-pollination. In order to increase the chances of pollination the pollen is light, and can therefore float for a considerable time in the air and be carried to a great distance, while the stigmas are usually large and branched, to increase the amount of their surface.

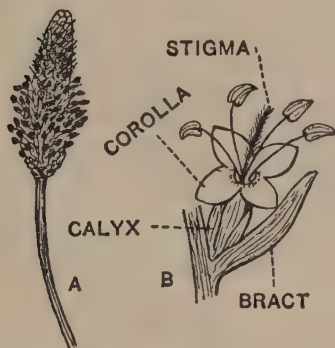


Fig. 60.

A, Spike; B, Flower of Plantain.

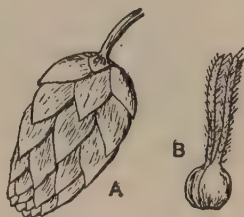


Fig. 61.

Hop. A, Female inflorescence; B, Pistil of Female Flower.

In many wind-pollinated trees the inevitable waste of pollen is to some extent reduced by the flowers opening before the leaves have unfolded, or before they have grown large enough to form a serious obstacle to the wind-carried pollen. In most herbaceous plants with wind-pollinated flowers (*e.g.* Plantains, Grasses, Salad Burnet, Docks, Sorrels) the latter are carried up on a long stalk, well above the leaves, so as to expose them as freely as possible to the wind. It will be noticed that many wind-pollinated plants have the stamens and the pistil in separate flowers, either on the same plant or on separate plants, and that when they are both present in the same flower the stigma nearly always matures before the anthers open; most Grasses, however, are protandrous.

226. How Fruits are Formed.—The influence of fertilisation extends from the developing seeds to the surrounding parts, causing a renewal of active growth not only in the carpels, but often in other parts of the flower as well. Usually

however, the stamens and corolla persist for a shorter time than they would have done had not fertilisation occurred.

The ultimate result of fertilisation is the formation of a fruit. The simplest definition of a fruit is that it consists of the parts of a single flower which persist and grow after fertilisation. This definition covers most fruits, which may be divided into *simple* and *aggregate*. A simple fruit is formed from one free carpel, as in the Bean, or from several united carpels (syncarpous pistil), as in the Poppy. An aggregate fruit is formed from several free carpels, as in Buttercup and Blackberry. The wall of the ovary becomes the *pericarp*, or fruit-wall, which may, as the fruit ripens, either remain soft and fleshy or become dry and hard.

Whether the fruit is dry or fleshy depends on the amount of water it contains when ripe. Dry fruits which contain several seeds usually open so as to set the seeds free, the pericarp breaking apart to form an opening. Some dry, many-seeded fruits, however, split into pieces, each containing a

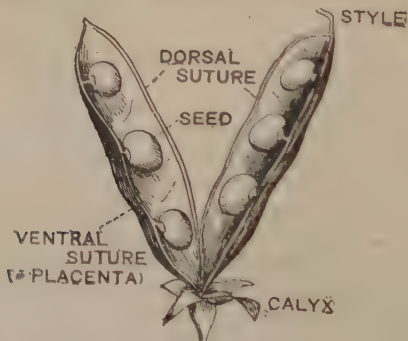


Fig. 62.—Ripe Carpel of Pea split open and showing the Seeds.

single seed. These two types are distinguished as (1) Opening or Capsular fruits; (2) Splitting or Separating fruits. Dry one-seeded fruits, and practically all fleshy fruits, remain closed, and the seeds escape by the decay of the pericarp, or the latter may only be broken when the seed germinates. This third type may be called (3) Closed or Indehiscent fruits.

227. Opening or Capsular Fruits.—The **follicle** opens along the inner side (*ventral suture*) which bears the seeds, *e.g.* in Monkshood, Marsh Marigold, Winter Aconite, Christmas Rose, Columbine, Larkspur (all belonging to the



Fig. 63.—Fruit of Wallflower.

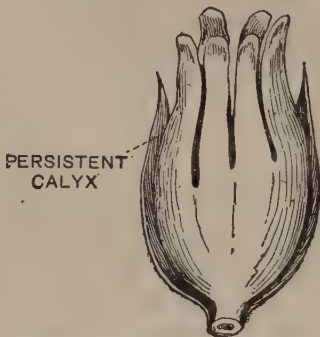


Fig. 64.—Capsule of Stitchwort opening by Six Teeth.

Buttercup family), also in Magnolia, Stonecrop, etc. The **pod** separates into two valves by opening along both dorsal and ventral sutures (Fig. 62). The **siliqua** (characteristic fruit of Crucifers) opens by two valves which separate from below upwards, leaving the seeds on the edges of a partition across the fruit (Fig. 63). The **silicula** is a short and broad form of the siliqua (Shepherd's Purse and other Crucifers).

A typical **capsule** usually consists of several carpels, and is dry. The capsules of Horse Chestnut are rather fleshy when ripe, and the fleshy capsules of the Balsam and Wood Sorrel are so much stretched when ripe that a touch is sufficient to cause them to split open and throw the seeds out violently.

Capsules usually open longitudinally, either along the dorsal sutures (midribs) of the carpels (*e.g.* Willow-herb, Blue-bell), or (more rarely) along the partitions between the chambers of the ovary (*e.g.* Foxglove, St. John's Wort). The capsule of Stitchwort (Fig. 64) and other Caryophyllaceae splits about half-way down into two



Fig. 65.
Transverse Dehiscence of Capsule of Plantain.

as many teeth as there are carpels. In all these cases the opening takes place along lines already marked out in the structure of the ovary; but in some plants it follows entirely new paths. Thus some capsules open transversely, a lid being separated, as in Plantain (Fig. 65), Pimpernel, Henbane; while in the Poppy small pieces of the capsule-wall are detached, forming a series of holes around the top of the capsule, through which the seeds escape.

Closed (indehiscent) fruits may be either dry, in which case they are usually one-seeded, or fleshy.

228. Dry Closed Fruits or Akenial (Achenial) Fruits are given various names, but the chief types are (1) **akene** (or **achene**), with membranous or leathery pericarp—*e.g.* Buttercups, Little Celandine, Anemone, Cinquefoil; the akene of Composites (Daisy, Dandelion, etc.) only differs in being produced from an inferior ovary; (2) the **grain**, in which pericarp and seed-coat are firmly united—Grasses; (3) the **nut**, with hard pericarp (the term is usually applied to all large or hard-coated akenes)—*e.g.* Hazel, Oak, Beech, Sweet Chestnut, Hornbeam; (4) the **samara** or winged akene (or nut)—*e.g.* Elm, Birch, Ash. The akenes of Composites and Valerians often have a tuft of hairs, usually sessile but stalked in Dandelion and Goat's-beard, called the **pappus** (= calyx), at the top; those of Clematis have a long plume (= style), those of Avens a hooked style.

229. Fleshy Fruits.—A few fleshy fruits open to let the seeds escape—*e.g.* Horse Chestnut, some Gourds, Balsam. Three chief types of closed fleshy fruits can be recognised: (1) the **berry**, in which the pericarp is soft and fleshy throughout except for the membranous or firm skin; (2) the **drupe**, in which the innermost portion of the pericarp forms a hard stone (endocarp) embedded in the fleshy middle portion (mesocarp), with a membranous skin (epicarp) on the outside; (3) the **pome**, which is intermediate in character between the drupe and the berry, and may be regarded as a special form of the latter.

230. Drupes ("stone fruits").—A simple drupe is formed from a single free carpel, and has one stone with one

seed inside it—*e.g.* Plum, Cherry. Drupes may, however, be syncarpous, in which case each chamber of the ovary may form a distinct stone or drupe. The so-called “berries” of Holly, Dogwood, and Elder are really compound drupes of this kind. The Walnut is a drupe from which the mesocarp (flesh) peels off during ripening, and allows the stone, enclosing a single seed, to escape. The drupe of the Almond has a velvety skin and rather tough mesocarp, which splits along one side; the endocarp is pitted and brittle, and there are sometimes two seeds inside it. The Coco-“nut” is a drupe in which the mesocarp (removed before exportation) is fibrous. The “shell” is the endocarp, and the flesh inside it is the endosperm in which lies a small embryo (below one of the three pits at the broader end of the “nut”); the fruit is formed from a three-chambered ovary, only one chamber being fertile; the space in the centre of the “nut,” filled with sap, corresponds to the cavity (vacuole) in the young embryo-sac.

231. Berries usually contain several seeds, but sometimes only one, as in Dogwood and Date. The Berry is distinguished from the drupe by the fact that the pericarp or “stone” has no hard part, whilst the stone in a drupe is the innermost part of the fruit-wall, and encloses the seed; the seeds (“pips”) in a berry may have hard coats, but the fruit has no other hard parts.

The Banana, Currant, Cucumber, Grape, Gooseberry, Orange, Pomegranate, Bilberry, Bittersweet, and Tomato are all berries, although several of them exhibit special peculiarities. In the case of the Gooseberry and Pomegranate, the outer layer of the coat of each seed is succulent, and forms a large part of the fruit. The “quarters” of the Orange, Lemon, “Lime-fruit,” and “Grape-fruit” correspond to the carpels, and the juicy part is composed of large hairs, which arise from the walls of the carpels and are filled with watery sap. The squirting Cucumber (*Ecballium*) becomes highly tense and turgid when ripe, so that when detached from the stalk the seeds are violently ejected along with a quantity of watery sap.

232. Pomes.—The Apple or Pear affords the best example of a pome, being developed from an inferior ovary composed

of five imperfectly syncarpous carpels. The outer fleshy part of an apple is really a portion of the receptacle, while the parchment-like membrane which forms around the wall of each chamber of the ovary is mainly carpellary in origin, the "pips" being of course the seeds. Pomes also occur in Rowan, Hawthorn, Quince, Medlar.

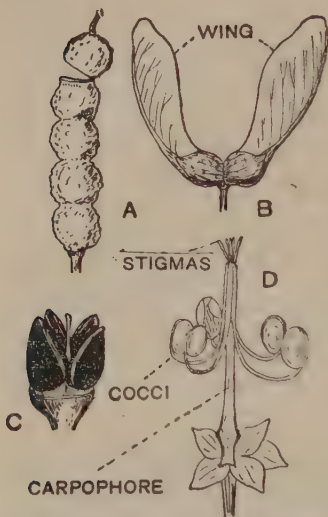


Fig. 66.—Schizocarps splitting into several pieces.

A, of *Hedysarum*; B, of *Maple*; C, of *Lanium*; D, of *Geranium*.

233. Splitting or Separating Fruits (Schizocarps) are so called because they split into two or more one-seeded parts (akenes or nuts). Examples are seen in Sycamore and Maple (Fig. 66 B), Umbellifers (Fig. 67), *Geranium* (Fig. 66 D), the Labiate and Borage families (Fig. 66 C), Mallow (Fig. 68).

In some Leguminosae (e.g. *Hedysarum*, the "French Honeysuckle") and some Crucifers (e.g. Radish) the fruit splits across into one-seeded pieces, and is called a **lomental**

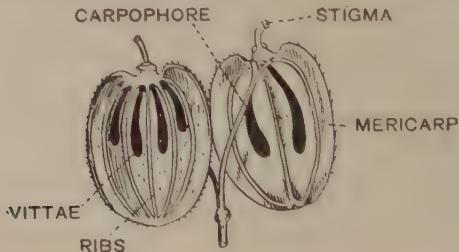


Fig. 67.—Schizocarp of *Heracleum* (Cow Parsnip).

(more strictly, a lomentalaceous pod, or siliqua, as the case may be), Fig. 66 A.

The one-seeded parts into which a schizocarp splits do not usually open to let the seed out; but this does occur in some cases—*e.g.* Spurges, Geranium (Fig. 66 D).

234. Aggregate Fruits may consist of a number of follicles, as in Christmas Rose, Marsh Marigold, Monkshood, etc., or of a number of akenes inserted on a convex receptacle, as in Anemone or Strawberry, or inside a concave receptacle, as in Rose, or they may consist of drupes on a convex receptacle, as in the Blackberry or Raspberry. Notice in each case whether the receptacle is dry or fleshy.



Fig. 68.—Schizocarp of Mallow.

235. Special Types.—The fruits developed from a group of flowers or dense inflorescence are often aggregated in closely packed clusters, such as are formed by the fleshy red berries of the Honeysuckle and by the clustered fruits of the Mulberry, the perianths of whose flowers become fleshy and enclose the carpels (Fig. 69 B). The Pineapple is a spike-

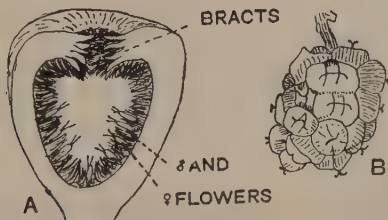


Fig. 69.—A, Fruit of Fig cut in half vertically; B, Fruit of Mulberry.

like inflorescence, in which the axis becomes fleshy during ripening, and the individual fruits fuse together. The Hop has an inflorescence consisting of an axis bearing membranous scales, in the axil of each of which there are two female flowers (Fig. 61); the scales are shed when ripe with the fruits attached to them. The Fig is formed by

a hollow, pear-shaped capitulum bearing male and female flowers, the "seeds" being really akenes (Fig. 69 A). The Date is a berry, the hard stone being the seed. The Banana is also a berry which, owing to cultivation, does not produce seeds.

236. Dispersal of Seeds and Fruits.—Such a plant as a Cherry tree may produce thousands of fruits and fertile seeds in a single season, although none of the latter may succeed in establishing themselves as young seedlings beneath the shade of the parent tree. Even if the parent plant is cut down, or dies at the end of the season, it can hardly make room for more than one or two of its offspring. Hence it is of the utmost importance that the seeds should be afforded some chance of distributing themselves, and reaching localities suitable for the development of new trees. Animals, and especially birds, act as the dispersing agents in this case, frequently carrying the fruit to a distance, and rejecting the hard and inedible stone which protects the seed.

Even in the case of annual plants, the dispersal of the seeds is of great importance, for it is evidently impossible that the thousand or so seeds which a single Sunflower may produce can germinate and become healthy seedlings on the same area that the adult plant occupied. The means of dispersal adopted by different plants vary widely, and are frequently such as to secure the almost ubiquitous distribution of particular plants. The four commonest agencies by which dispersal is secured are: **wind, water, animals, and explosive mechanisms** in the fruit itself.

237. Dispersal by the Wind is facilitated by the minuteness or lightness of the seeds or fruits, and by the presence of tufts of hairs or wing-like membranes which increase the surface exposed to the wind without appreciably adding to the weight. It is only in the case of dehiscent fruits that mechanisms for dispersal are borne by the seed; closed fruits and the segments of splitting fruits are themselves distributed and possess contrivances for dispersal, while the seeds have none and are carried inside the fruit. The seeds of Orchids are so small and light that, when they

are set free by the dehiscence of the capsules, they are freely blown about by the wind. Hence the readiness with which aerial Orchids establish themselves afresh upon the trunks of tropical trees.

When the seeds are larger and heavier, the fruit frequently opens in such a manner that the seeds can only escape a few at a time and are jerked out when strong winds rock the capsules to and fro. This **censer mechanism** is seen in follicles and many capsules, *e.g.* those of Poppy and *Campanula* (Harebell, Canterbury-bell), which open by pores; those of Campions, Stitchworts, Primroses, etc., which open by teeth at the top; besides in capsules opening by slits or a lid; also in the fruiting heads of Composites which have no pappus on their akenes, *e.g.* Sunflower.

As an aid to wind-dispersal, seeds are frequently flattened (Wallflower, Iris, etc.), as also are the fruit-segments of Umbellifers and the akenes of Buttercups and Composites.

Very commonly, however, special structures are present which enable seeds, or more frequently akenes, to be more readily carried by the wind. The seeds of the Willow, Poplar, Willow-herb (*Epilobium*), Bog Asphodel, and Cotton-plant have hairy outgrowths, the seeds of Pines are winged, as also are those of "Honesty," Yellow Rattle, *Deutzia*, and of certain tropical Bignonias ("Trumpet-flower"). The winged akenes (samaras) of the Ash, Elm, and Birch afford good examples of winged fruits in which the wing is an outgrowth of the pericarp. In the Maple and Sycamore each fruit splits into two or three winged samaras. The Hornbeam (Fig. 70) has persistent bracts which form a wing on the fruit; a similar bract-wing occurs in the Hop. In the Lime-tree (*Tilia*) the stalk bearing the cluster of nuts hangs down, and the large bract attached to it acts as a kite or aeroplane.

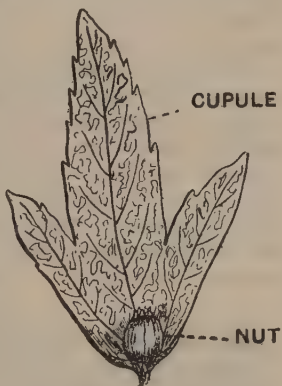


Fig. 70.—Fruit of Hornbeam.

Bracts also act as wings to the fruits of *Bougainvillea* and *Mirabilis* (Marvel of Peru)—two tropical but commonly cultivated plants. In Docks the fruit is covered by the "calyx," which bears three wings. In some cases the wing is funnel-shaped, or parachute-like, as in Thrift (persistent papery calyx) and Teasel (persistent bracts around the flower).

A few examples of plumed fruits (*i.e.* fruits bearing hairs or hairy appendages) may be given. In *Clematis* and some *Anemones* (*e.g.* Pasque-flower) each achene has a persistent hairy style; in Cotton-grass the fruit bears numerous long silky hairs, produced by the "calyx"; in Bulrushes hairs are produced by the stalk on which each fruit is carried. The most highly developed plumed fruits occur in Valerians and many Composites; in these plants the calyx grows after fertilisation, and forms a ring of hairs (the pappus) on the top of the fruit. Good examples are seen in the Dandelion and the Goat's-beard, where the pappus forms a parachute carried on a stalk. If the air becomes moist the parachute closes up, and the fruit falls to the earth, and is washed into the soil by the first shower of rain.

Dispersal by wind involves a greater loss of seeds than dispersal by animals, for the latter usually frequent fertile localities where the seeds have a chance of germinating, whereas wind-dispersed seeds may fall upon sterile or unsuitable localities, or may be carried out to sea. It is for this reason that winged and hairy seeds are usually absent from the plants of the seashore. Hence also arises the fact that wind-dispersed seeds are usually produced in relatively greater abundance than those dispersed by animals.

238. Dispersal by Water is uncommon, and occurs chiefly in aquatic plants. Seeds may also be carried on the mud adhering to the feet of aquatic birds. In plants which grow on the margin of streams, as well as in those aquatics whose leaves are aerial (*e.g.* Water Plantain, Arrow-head), the seeds may fall into the water. In some cases (*e.g.* Alder) the seeds are enabled to float to a distance by being provided with a spongy covering which contains air. This is the case in Water Lilies, but in these—and in most submerged or floating water-plants—the fruits are developed under water, and

are either achenes, nuts, or splitting fruits which separate into hard one-seeded parts.

239. Dispersal by Animals may be either passive or active. Many fruits possess hooks, and hence may adhere to the wool or fur of passing animals. These adhesive contrivances are usually outgrowths of the fruit and not of the seed. Examples are afforded by *Avens* (hook = persistent style on each achene); *Goosegrass*; *Carrot*, *Medick* (pod coiled, bearing hooks); *Hound's-tongue*; *Sanicle*, *Chervils*, and a few other *Umbellifers*; *Agrimony* (hooks on receptacle); *Enchanter's Nightshade* (Fig. 51). The flower-heads of *Teasel* and *Burdock* have hooked bracts so that a passing animal may catch the plant and drag it forward, the rebound causing the fruits to be jerked out; or, in *Burdock*, whole burs (fruit-heads) may thus catch on to the animal and be carried off. In *Burweed* (*Xanthium*, a curious Composite, found in South England but not native, with small heads of unisexual flowers) the female flower-head is covered with hooked prickles and ends in two short conical beaks; and in *Bur-marigold* (*Bidens*) each achene has a pappus of two or three stiff bristles covered with small downward-pointing prickles. The most formidable hooked fruits occur in tropical plants such as *Martynia* and *Harpagophytum*, which are usually shown in botanical museums. Hooks and spines also serve to protect fruits against animals which might otherwise eat them; this is probably the case with the spiny capsules of *Horse Chestnut*, the stiff bristles (awns) of *Barley*, etc.

Active dispersal takes place when animals seek out fleshy fruits in order to devour them. The seeds are protected by hard stones in the case of drupes (*Cherry* or *Plum*), or by thick leathery seed-coats in the case of most berries, by the pericarp in aggregate fruits such as the *Strawberry* or the hip of the *Rose*. In most cases the covering of the seed is hard and quite indigestible, and in not a few cases the seed itself is poisonous. Hence in many cases the seed can pass through the animal's body without being injured, and if deposited in suitable soil may succeed in germinating. Very often, however, the hard part of the fruit is never swallowed, but allowed to fall to the ground after the soft part has been pecked; for the animals concerned in this mode of dispersal are usually birds, whose gizzards may crush small seeds and destroy them.

The fleshy part of the fruit is usually conspicuously coloured, and may be produced from almost any part of the flower: from the ovary-wall (*Cherry*), the receptacle (*Apple*, *Strawberry*), the perianth (*Mulberry*), etc. Sometimes the seed has a coloured fleshy aril or extra seed-coat—e.g. *Spindle-tree*, *Yew*, *Nutmeg* ("Mace" = aril). Most, but by no means all, fleshy and bird-dispersed fruits occur on trees and shrubs (why?).

Dry fruits (*Acorns*, etc.) may also be actively dispersed by such animals as *squirrels*, etc., for these animals often forget some of the hoards they lay up in autumn. This is, however, an accidental mode of dispersal, and, except in the presence of a hard pericarp, the structure of the fruit shows no special adaptations which might render this kind of dispersal more constant and profitable.

240. Explosive Fruits.—Some fruits show active movements by which the seeds are scattered or flung out suddenly. The Squirting Cucumber has already been mentioned. In Balsams the fleshy capsules have swollen and stretched walls, so that a slight disturbance causes the capsule to burst, and the seeds are thrown a few feet away. The seeds of Wood Sorrel have a fleshy aril, which is very elastic, and when the capsule opens the aril suddenly turns inside out and jerks the seed away.

The capsule of the Pansy splits into three boat-shaped parts, whose edges roll together in drying and squeeze the polished surfaces of the seeds, causing the seeds to jump away. In *Geranium* (Fig. 66 D) the carpels split apart, and the style splits off a slender thread attached to each carpel; these threads suddenly curl upwards and outwards, so as to throw the seeds out. The ripe pods of Gorse and of Broom suddenly burst open with an audible crackling noise, the two valves becoming twisted and the seeds scattered; this can easily be observed on a warm day. More or less similar explosive mechanisms occur in some other Leguminous plants (*Lupin*, *Vetches*, etc.), also in *Box-tree*, *Spurges*, *Hairy Bittercress*, and in many tropical plants.

241. Seeds.—It will be noticed that the life-history of a flowering plant which reproduces itself by seed is divided into two periods, one short and the other long. The fertilised germ proceeds as far as the production of what is usually recognisable as a young plantlet, and then stops, the further life-history of the plant not being resumed until the seed germinates.

The quiescent period may be of great length, for seeds have been known to germinate after being kept dry for over fifty years, although those of other plants may perish after a few weeks. Furthermore, the difference between endospermic and non-endospermic seeds simply consists in the fact that, in the latter case, all the available food materials are absorbed by and stored up in the young seed as it ripens, whereas in the former they are not absorbed until the seed germinates. In correspondence with this fact, the young embryo is usually much less developed in endospermic than it is in non-endospermic seeds.

The structure of the seed is best made out by the examination of thin sections. Rather puzzling appearances are, however, presented when the embryo is curved or twisted instead of being straight, or when the cotyledons are folded, or divided into lobes, for in such cases the same part may be cut twice in the one section.

In some seeds special outgrowths or **arils** are formed at the point of attachment of the seed and funicle, or from the surface of the seed. These assume the form of wartlike, fleshy excrescences in the seeds of the Pansy, Castor Oil plant, and the Spurge. In the Willow and Poplar the aril is represented by a tuft of hairs which grow out from the funicle. Occasionally the aril forms an irregular fleshy investment to the seed, an example of which is afforded by the mace of Nutmegs. The succulent part of the red "berry" of the Yew is simply a special kind of aril, as is shown by its mode of development.

242. Practical Work on Fruits and Seed-Dispersal.—

Collect all kinds of fruits, belonging to both wild and cultivated plants, and arrange them according to (1) their structure, (2) their adaptations for seed-dispersal. Make sketches of all the fruits you examine; cut them across or open them up to make out the structure. Distinguish between one-seeded fruits (akenes, etc.) and true seeds, and notice which part of a fruit is fleshy, which part forms wings or tufts of hairs, etc. Carefully notice and compare the times taken for a winged or plumed fruit or seed to fall to the floor (1) with the wings or plumes still on it, (2) after removing them. Watch the scattering of flattened, winged, and plumed fruits and seeds on a windy day. Why do some winged fruits—*e.g.* Ash- and Sycamore—"keys"—whirl round while being blown away, and what are the advantages of this?

QUESTIONS ON CHAPTER VI.

1. What is the usual function performed by the various parts of the flower? Have you observed any cases in which functions other than the usual ones are performed by floral structures? Show by several examples that the division of the flower into four whorls cannot always be rigidly maintained.

2. Give an account of the structure and function of a pollen-grain.

3. Describe the processes which lead to the conversion of an ovule into a seed, and state what is the difference between albuminous (endospermic) and exalbuminous (non-endospermic) seeds, giving examples.

4. Describe the situation in which honey is produced in any three flowers you have examined. How does it profit a plant to expend its substance in the production of honey? How is it that some plants dispense with the production of honey? Name three such plants.

5. Draw the flowers of any three of the following:—Figwort, Snapdragon, Foxglove, Salvia, Monkshood, Sweet Pea, Dead-nettle. What do you know of the method of pollination in the flowers you draw? Explain the connection, if any, between the methods of pollination and the time of year at which the flowers appear.

6. Mention a flower which is naturally self-fertilised, and another which is naturally cross-fertilised. What could you do to aid cross-fertilisation in the first, and self-fertilisation in the second case? Is the seed produced by cross-fertilisation better or worse than that produced by self-fertilisation?

7. Briefly describe, giving examples, the following forms of inflorescence, and point out the relationship which exists between them:—spike, spadix, raceme, head, panicle, umbel.

8. State what is the essential difference between *definite* and *indefinite* inflorescences, describing, with examples, the principal varieties of each (definite = cymose, indefinite = racemose).

9. What is meant by a floral receptacle? What part does it play in our conception of the structure of the flower?

10. Name any plants you know in which the flowers are massed in close, flat-topped inflorescences, and mention the advantages which you suppose are obtained by such an arrangement. Name any natural orders that are characterised by this type of inflorescence, and describe, with instances, the differentiation (modification) which the marginal flowers may undergo.

11. What flowers have you yourself observed being visited by wasps, by butterflies, by flies? What insects have you yourself seen at Sweet Pea, Primrose, Buttercup? Supplement this answer by information obtained in other ways, but distinguish carefully between observations and theories, facts and expectations.

12. Describe the inflorescence of a Daisy and of a Dead-nettle, pointing out the features of (a) resemblance, (b) difference, existing between them.

13. Describe the process of pollination in any *two* of the following:—Larkspur, Willowherb (*Epilobium*), Dead-nettle, Willow.

14. Describe any arrangements which are adapted to secure cross-pollination in three different Ranunculaceous flowers.

15. Describe the flowers of the Primrose, and explain the adaptations for pollination.

16. What is heterostylism, and what is its importance? Give examples of heterostyled British plants.

17. Mention any flowers you know which are pollinated by the wind. Describe the structures involved in pollination in each case, and show how they differ from the corresponding structures in insect-pollinated flowers. Have you noticed any other features of wind-pollinated flowers, such as habitat or time of flowering, which you can connect with wind-pollination? Give instances.

18. Describe the changes which an ovule undergoes in becoming a seed.

19. Distinguish between syncarpous and apocarpous fruits, and give examples of common table fruits under both heads.

20. Compare carefully the flower and fruit of a Rose with those of a Buttercup, and explain, by means of diagrams, the principal differences between them.

21. Show by comparative drawings of the flower and fruit of the Apple, the Rose, the Blackberry, the Plum, and the Strawberry just what parts of the flower and fruit correspond to one another in each case.

22. Mention two plants, each of which possesses a persistent calyx. Fully describe the calyx, and explain its use to the plant in both cases.

23. Describe and compare the fruits of the Rose, Fig, Strawberry, and Mulberry.

24. Give instances of seeds or fruits which are dispersed (a) through the agency of the wind, and (b) through the agency of animals. Of what advantage is it to plants that their seeds should be thus dispersed?

25. Describe examples of fruits or seeds which are dispersed by water, pointing out any adaptations for this method of dispersal.

26. Give an account of the various ways in which seeds are protected during the period of ripening.

27. Describe with the help of drawings five different devices by which seeds are scattered. Describe any experiments you have made on the scattering of seeds.

28. Mention any fruits or seeds you know which are distributed by the agency of animals. Describe the structures used in five cases. Have you made any personal observations on such distribution?

29. Write a short account of the structure of the more common dry dehiscent fruits, and explain how the seeds are scattered in those examples which you describe.

30. Describe examples of explosive fruits, and try to explain the mechanism in each case.

CHAPTER VII.

SWEET PEA, VETCHES, CLOVERS, SCARLET RUNNER, GORSE, LABURNUM.

243. The Study of Typical Plants.—In the remaining chapters we shall study various common plants as “types.” *Each of these plants should be studied throughout its life history.* The best way is, of course, to make repeated visits to the growing plants at short intervals, day by day (and at different times of the day in some cases), week by week, month by month, throughout the year. In any case—more especially if these frequent visits cannot conveniently be made—dig up the smaller plants and keep them under continuous observation, indoors or in a garden, making notes and sketches of the various stages in the progress of the plant’s growth and development. Sow the ripe seeds of each plant and study the stages of germination and the growth of the seedling into the mature plant. Carry out all the experiments mentioned in connection with each plant and any others which suggest themselves as being likely to yield answers to the innumerable questions arising from the study of the plant itself.

Among the many points to be attended to, the following may be mentioned:—

(1) The habit (form and general appearance) of the plant—*e.g.* tree, shrub, climbing, creeping, rosette-form, erect herb, bulb-forming—and the advantages and disadvantages of the habitat.

(2) The habitat (place of growth)—*e.g.* hedge-row, field, marsh, ditch, pond, stream, wood—and the adaptations to the habit.

(3) The conditions of growth as regards soil—*e.g.* sand, clay, loam, chalk, moistness or dryness of soil, presence or absence of humus.

(4) The light-conditions—whether deeply or partially shaded or in full light.

(5) The associated plants and *their* habits.

(6) The characters of the vegetative organs of the plant—*e.g.* methods for reaching light and air, for spreading by runners, etc., for perennating, storage of food, form and texture of stem and of leaf, hairiness or smoothness, buds (structure, form of young leaves, unfolding), arrangement of leaves, form of blade, lengths of leaf-stalks, movements of young or adult leaves, abundance or scarcity of stomates on upper and lower surfaces of leaf, methods by which young or adult leaves are protected against excessive transpiration, etc., leaf-mosaics.

(7) The characters of the reproductive organs (note any means of vegetative propagation apart from the production of seeds)—*e.g.* time of flowering, colour, scent, honey, mechanisms for promoting cross-pollination, kinds of insects seen visiting the flower if insect-pollinated, adaptations for insect-visits or for wind-pollination, movements of flower-parts or of flower-stalks and the reasons for the movements, structure of flower (dissect, cut longitudinal section, and draw these and also the ground-plan or “floral diagram” of the flower), stages in development of fruit, growth of ovary-wall after fertilisation and any changes in its texture and colour, growth of other parts (calyx, receptacle), structure of ripe fruit (sketch whole fruit and sections), time when fruit ripens, number and size of seeds, proportion of seeds to ovules, adaptations for seed-dispersal by birds or other animals, by wind, by mechanisms for ejection; whether plants grow singly or in colonies.

244. Trees and Shrubs.—There is no sharp distinction between herbaceous and woody plants, though the terms herb, shrub, and tree are convenient for general use. It is perhaps sufficient to define a woody plant as one whose stem persists above the soil year after year (as compared with a plant which dies down to the level of the soil, though the “root-stock” or rhizome is hard and woody), storing food in its stems and buds and the latter being protected in most cases by special scales. A tree usually possesses a stout, main trunk from which smaller and more slender lateral branches arise. Frequently, however, the main stem is short, and is exceeded in length by the branches. A shrub, on the other hand, is simply a miniature tree, the primary stem being usually short, and soon breaking up into numerous more or less erect lateral branches.

In studying trees, the following points should be attended to :—

(1) The general form and appearance as determined by the mode of branching, direction of the branches, and the character of the foliage.

(2) The nature of the situation and the character of the soil in which each species apparently thrives with the greatest luxuriance,

(3) The general effect of each kind of tree on the appearance of the landscape.

(4) The thickness of the trunk as compared with the size of the tree, and the character of the bark.

(5) The time of the appearance of the leaves, the form of the leaf, and the arrangement of the veins.

(6) The time of flowering and the nature of the flowers.

(7) The nature of the fruit and seed and the mode of dispersal.

(8) The germination of the seed and the form of the seedlings, which may often be found under the trees or at some distance from them; gather ripe seeds and study their germination.

Note whether the main trunk persists and runs up through to the top of the tree ("excurrent" or "spire-forming" habit, *e.g.* Larch) or whether it soon becomes lost in a complex of strong branches ("deliquescent" or "diffuse" habit, *e.g.* Beech); the form of the tree's crown, whether pointed, rounded, or umbrella-like; the arrangement of the branches, the angles at which they come off, their direction of growth; why branches at the top of a tree are usually more straight than the lower branches; why branches turn up at the ends in many trees; why branches rise upwards, or bend in towards the centre of the tree in winter (in deciduous trees). All these points, which, together with others, unite to give trees their general form, should be carefully studied. In many cases this is more easily done in winter, when deciduous trees show their bare branches.

Note also the depth of the shade cast by the tree when in full foliage, and the effect this has on the nature and habit of the plants forming the undergrowth; the mode of branching shown by the tree when growing with others in a clump or in a wood, and that shown by the same kind of tree when growing by itself in an open situation; the differences in size and in texture of the leaves well exposed to light, and of those growing in shade; the tendency of the leaves on each twig to form a "leaf-mosaic" (*i.e.* to vary in size and shape so as not to shade each other); the structure of the winter-buds, and the various ways in which the young leaves are folded up and protected.

Some further points relating to the biology of trees may be mentioned here. One often sees on high exposed places inland, as well as near the coast, trees which have grown obliquely, sometimes almost horizontally, after reaching a certain height; in other cases the trees growing in such situations are erect, but growth has occurred almost entirely on one side. If you see examples of such trees, try to discover the causes of their bent or one-sided growth. Note the direction of the bend or that of the well-grown side of the tree, then find out the directions and characters (whether dry or moist, cold or warm) of the prevailing winds. At what time of year will the prevailing wind have most influence on the tree's growth, and in what way?

245. Sweet Pea (*Lathyrus odoratus*).—We have already studied the germination of the seed (Art. 91). Get complete plants and study the stem, leaves, flowers, and fruits.

Note the green flattened stem, which is provided with a thin expansion (wing) on two opposite sides. Do the wings run straight along the main stem, always on the same sides?

Sketch a piece of the shoot bearing a leaf; note the stipules, the two leaflets, and the tendrils. What part of a leaflet does a tendril represent? What part is not developed in one of these leaflet-tendrils? Compare the ordinary leaf of Sweet Pea with the *young* leaves (Fig. 7) of Broad Bean. What advantage does the Sweet Pea lose by the development of its upper leaflets into tendrils? How is the loss of green tissue in this plant to some extent compensated? Examine the Everlasting Pea, which differs from the ordinary kind in being perennial (note the branched underground stem, and test its cut surface with iodine solution); how does its leaf differ from that of the common Sweet Pea? What is the advantage of winged leaf-stalks in Everlasting Pea?

Why does a Sweet Pea seedling fall over and sprawl about if no support, *e.g.* a stick, is placed near it? Place sticks in a pot of seedlings, also strings stretched between sticks and running horizontally and at different angles. Are the tendrils able to coil around horizontal supports as well as inclined or vertical supports? Sketch a young leaf with tendrils which have not yet come into contact with a support: are the young tendrils straight or curved? Is it possible to make a young tendril coil without providing it with a support? Try the effect of stroking a young tendril with a stick, a string, a glass rod; stroke it at different points. Which part of the tendril is sensitive to contact and responds by coiling?

Examine flowers of different ages, making observations as directed for Broad Bean (Chap. I.). Dissect and sketch the flower and follow its development as fully as possible, from the time it opens until the ripening of the pod. The mechanism of the flowers is essentially similar to that found in the Broad Bean, but self-pollination usually occurs in the bud before the flower opens (Art. 195); verify this for yourself. Is the Sweet Pea visited by insects, and if so, by what kinds? How do florists get the numerous varieties of Sweet Pea for garden cultivation?

† Some plants allied to Sweet Pea are of great interest. Two species, though not very common, should be examined if possible. In

† Paragraphs and articles marked thus are intended chiefly for reference, and may be omitted on first reading of the book.

the Yellow Vetchling (*Lathyrus aphaca*, Fig. 71) note the complete

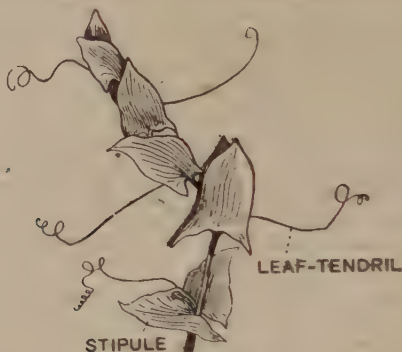


Fig. 71.—*Lathyrus aphaca*.

absence of ordinary leaflets, the whole of which are developed as tendrils, and the very large stipules (why so large?). In the Grass

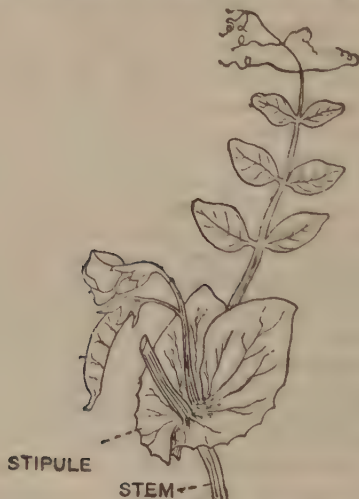


Fig. 72.—Part of a Garden (Eating) Pea Plant (*Pisum sativum*).

Vetch (*L. nissolia*, found chiefly in the south of England) the plant appears to have long grass-like leaves, but close examination shows

that the apparent leaf is really a flattened leaf-stalk, and no leaflets are present. The Grass Vetch does not climb, but it grows among grasses and gains some support in this way; does its growth among grasses explain the long narrow form of its flat leaf-stalks (technically called *phyllodes*)?

The Garden or Eating Pea (*Pisum*) should also be examined and its leaves and flowers compared with those of Sweet Pea (Figs. 72, 73).

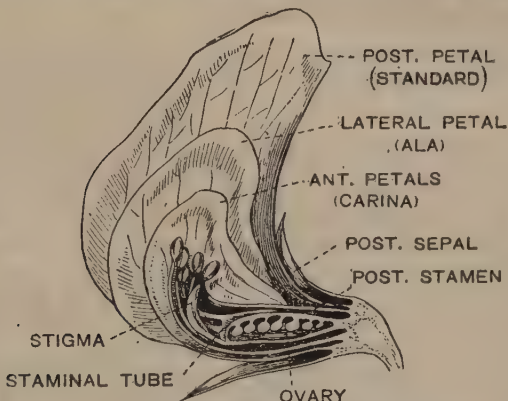


Fig. 73.—Median Section, Flower of Garden Pea.

Ala = wing-petal, carina = keel.

246. Vetches.—The true Vetches are allied to the Broad Bean, forming the genus *Vicia*. The **Common Vetch** or **Tare** (*Vicia sativa*), or one of the other species, should be studied as a type; the Vetches differ from the Broad Bean (*Vicia faba*) in being tendril-climbers, like the Sweet Pea.

The Common Vetch has long been cultivated for fodder, and has become so widely distributed that besides growing in cultivated fields it is frequently found in waste places and woods. It is sometimes sown with Rye, the stems of which serve as supports for the tendrils. It is easily distinguished from the other Vetches by its red flowers, carried singly or in pairs in the axils of the upper leaves.

Examine plants found in fields, hedge-rows, and other localities, noting whether the stems are short and spreading or long and erect. Sketch a piece of the plant, showing the form of the stem; the leaves, each having 3 to 5 pairs of

leaflets and ending in tendrils (modified leaflets); the flowers (spring and early summer) and the pods. Examine the flower carefully and compare its structure with that of the Broad Bean and the Sweet Pea; note the tuft of hairs below the stigma, which is one of the characters separating the Vetch-and-Broad-Bean genus (*Vicia*) from the Sweet-Pea-and-Vetchling genus (*Lathyrus*).

Of the other vetches found in Britain the two commonest are the Tufted Vetch (*V. cracca*) and the Bush Vetch (*V. sepium*). The former, which flowers from July to September, is the most conspicuous of the wild Vetches, owing to its large masses of purple flowers and the height (6 ft. or even more) the plant reaches in climbing the hedges. It is a perennial plant, with a creeping "rootstock"; the leaf has numerous pairs of leaflets and ends in two or three tendrils, and the stipules are half-arrow-shaped. The inflorescence (a *raceme*) bears numerous flowers, each with a short stalk, and the flowers are turned towards one side of the inflorescence; this arrangement enables a bee visiting the inflorescence to visit several flowers in a short time.

The Bush Vetch flowers from April until October; it often grows in woods and on roadsides as well as in hedges. Like the Tufted Vetch it is perennial, but the stems are seldom over 2 ft. high, and the flowers (2 to 6) are in a very short raceme (as in Broad Bean).

In Tufted Vetch each wing-petal is united to the keel in two places, more firmly than in Broad Bean and Sweet Pea; the mechanism is similar, but the parts resume their former position more readily when the pressure is removed, *i.e.* when the bee leaves the flower. The flowers are small and visited by various insects, short-tongued as well as long-tongued. In Bush Vetch the flower-tube is longer and the flowers are therefore visited by fewer insects; apparently even humble-bees have to (or at any rate often do) bite through the side of the flower to get the honey.

In most Vetches the pod opens violently and expels the seeds, the two valves coiling suddenly as in Gorse and Broom.

247. White or Dutch Clover (*Trifolium repens*) is the commonest kind of Clover and is easily distinguished by its slender creeping branches (runners) and its ball-like clusters of cream-white flowers.

Pull up an entire plant, noting the wiry green runners which arise from the parent plant and creep in all directions, giving off at certain points ("nodes") a leaf and often a root. The roots, though slender, penetrate deeply into the soil; dig a root up, wash it, and notice the numerous tubercles, which are nearly always present on it, and the length of the much-branched root. Note the arrangement

of the leaves in two side rows on the stem, and the bending of the leaf-base which brings the stalk into a more or less vertical position. Examine plants growing in different localities, *e.g.* on waste ground, in garden borders, on lawns, on garden paths, under hedges, among long grasses, in exposed places, in dry or sandy soil, in moist rich soil.

The White Clover has several obvious adaptations or advantageous characters which enable it to struggle successfully for existence, as, indeed, *all* plants have. Its long runners enable it to spread rapidly along the ground, while its long roots reach a deeper water supply in the soil than do the roots of most grasses and other plants with which it has to compete. Its leaves can be altered in position by means of the leaf-base, which is capable of changing in shape so as to alter the direction of the leaf-stalk; the latter varies greatly in length, remaining very short when the plant is growing with short grasses, as on a close-cut lawn, but growing very long when among longer grasses, while the three leaflets spread out like an umbrella and catch plenty of light. The Clover is evidently a light-demanding plant, and it grows badly when overshadowed by long grasses in a field or by a hedge. Now compare the appearance (length of runners and of leaf-stalks, size of leaflets—in short, the general “habit”) of plants growing in different localities and see whether your observations bear out what has just been said about the biological advantages possessed by White Clover. Do not be content with merely reading about adaptations of plants, when it is easy to find out so much for yourself.

Note the three leaflets, arising close together from the top of the leaf-stalk; the swollen base of each leaflet; the shape of the leaflet—broadest at the free end (“obovate” or “obcordate”); the white spot or Λ -shaped patch at the middle of the leaflet; the midrib and the finer veins. Dip a leaf into boiling water: air-bubbles escape from both surfaces, and the white patches disappear. This shows that the leaflets bear stomates on both sides, and that the white patch is due to the presence of air. Microscopic examination of pieces of skin torn from a leaflet and of sections across a leaflet shows that there are numerous stomates on both surfaces (rather more on the upper surface than on the lower) and that the whiteness of the patch is due to reflection

from a layer of air below the skin, which is separated here from the inner tissue of the leaflet.

Note the small pointed stipules, which are joined around the stem at the base of the leaf-stalk. Examine the growing free end of a runner, and note how the stipules enclose and protect the youngest leaves and the growing-point of the runner. Note also the way in which the three leaflets of a young leaf are separately folded up: does the folding bring the upper or the lower faces of each leaflet together?

Have you ever noticed that Clover leaves become folded up at night? The "sleep" movements of Clover are easy to observe if you visit the plants at dusk, or later with a lantern, and in addition make a few simple experiments. In the sunlight the three leaflets spread out more or less horizontally from the top of the leaf-stalk. When closing begins the leaf-stalk becomes erect, then two of the leaflets droop and at the same time rotate until they stand in the vertical plane, with their upper surfaces in contact, and finally the third or "end" leaflet swings over, describing almost a semi-circle and at the same time becoming folded along its midrib so as to cover the other two leaflets like a roof, its lower surface being of course on the outside. The result of these movements is to conceal the upper faces of all the leaflets, at the same time bringing them into the vertical position.

From your knowledge of plant physiology, you will realise the usefulness of these movements as a protection against excessive loss of moisture and of warmth. If the leaves are prevented from moving, and caused to remain in the horizontal position, by being pinned to a piece of cork, they lose water and warmth, and (especially on a clear cold night) may be injured or even killed. Clover leaves fixed horizontally in this way show drops of dew on the leaflets when examined in the morning, while untouched leaves remain quite dry.

Many experiments on the sleep movements of Clover and other plants are given in *The Power of Movement in Plants*, by Charles and Francis Darwin. Professor Miall describes these movements in Clover and Wood Sorrel in his *House, Field, and Garden*.

Several questions arise from observation of the sleep movements of Clover leaves, and these questions can be answered, *partly* at any rate, by a few simple experiments.

First, to what external stimulus, or stimuli, are the movements due? If it is darkness alone which induces the movements, it should be possible to make the leaves "sleep" in the daytime by covering up a plant so as to exclude light from it. Invert a flower-pot over a Clover plant growing out of doors, heaping soil around the rim so as to keep light out. How long does it take for the leaflets to assume the night position? The experiment can be made indoors with a plant dug up and put into a flower-pot, or even with single leaves cut off and set in a bottle of water. If you have a pair of coloured bell-jars (red and blue) or, better, a pair of hollow bell-jars containing coloured solutions (see Art. 126 *b*),* you will find that the plants receiving red-orange light show the "sleep" movements, while those in blue-violet light do not—red-orange light acts in this case like darkness, blue-violet light like sunlight. Has *cold* any share in causing the movements? Get two dug-up Clover plants and set them in glass jars, surrounding one jar with pieces of ice, then expose both to sunlight. Another method is to use single leaves, putting some into a bottle containing water kept cold by adding pieces of ice, while the water in the other bottle is at the ordinary temperature. Does warmth hasten the "opening" of leaves which have assumed the night position? Try a simple experiment with "closed" leaves, setting some in warm and others in cold water.

Second, by what mechanism are the movements caused, and where do they take place? If you carefully examine leaves in different stages of movement, you will find that the broad thin parts—the blades—of the leaflets do not change in form (except for the folding-up of the end leaflet to form a roof over the other two), so that the actual movement has its seat in the short cylindrical stalk which joins the leaflet to the main leaf-stalk. This can be proved by (1) clipping a leaflet off just above its base, (2) clipping away the thin green portion of the blade of a leaflet and leaving only the midrib. In both cases the parts left will perform the movements, as if the leaflets were still present. For comparison

* The solution of potassium dichromate allows the red and orange light rays to pass, while the copper sulphate solution transmits chiefly the blue rays.

with Clover, study the sleep movements of the Wood Sorrel (Art. 268) and of the Bird's-foot Trefoil (*Lotus corniculatus*).

The flowers of the Clover are arranged in globular heads, $\frac{3}{4}$ to $1\frac{1}{2}$ inch diameter, each head being carried on an erect branch, usually from 3 to 6 inches long, which arises in the axil of a leaf. The calyx-tube is colourless, with five green pointed teeth rather shorter than the tube itself, the lowest tooth being the shortest. The petals are white, creamy, or reddish in colour; the wing-petals are joined firmly to the keel. The corolla is short enough for hive-bees to reach the honey (Clover forms an important source of honey, like Ling, Winter Aconite, and Crocus). When the keel is pressed down the stamens and stigma emerge from it, but they resume their former position when the bee flies away, so that the same flower may be visited several times. Each flower has a short stalk of its own, and after the flower has been pollinated the stalk lengthens and bends downwards, so that the pollinated flowers are placed out of the way of the bees and room is made for the younger flowers.

The pod, containing 2 to 4 seeds as a rule, projects beyond the calyx, but is covered by the withered standard-petal.

248. Red Clover (*Trifolium pratense*) differs a good deal from White Clover. It is a larger, coarser, and more compact plant: its "rootstock" or "rhizome" is short and thick; its leafy shoots are covered with soft hairs; its leaves and flowers are larger; it has no runners.

Dig up a plant, noting that all the spreading aerial shoots arise from the thick main stem ("rootstock"); cut the latter across and test the cut surface with iodine solution, noting the abundant starch. The plant is perennial, but generally lasts only a few years. The leafy shoots, which may reach a length of two feet, bend outwards from the "rootstock," but soon grow erect, giving the whole plant a tufted habit. The stalks of the lower leaves are long, those of the upper leaves short. Notice the large stipules (often over an inch long), continuous with the sheathing leaf-base; each has green streaks (veins), ends in a long pointed tip, and is hairy outside while the inside is smooth and shiny. Pull off the leaves from a bud or young leafy shoot and notice how the stipules protect the young leaves. The leaflets are folded along the midrib so that the upper surface of each is

on the inside of the fold. The leaflets ($\frac{1}{2}$ to 2 ins. long) are oblong, with the edges finely toothed; there is usually a Λ - or $\wedge$ -shaped whitish patch about the middle.

The flowers are in dense globular or egg-shaped heads (diameter $\frac{1}{2}$ to $1\frac{1}{2}$ ins.), and are usually red-purple, but sometimes very pale red or even white. A little below the head there are two leaves differing from the ordinary foliage-leaves in having no stalk or a very short one and in having larger stipules; these two leaves fold over and protect the young flower-head. Just below the flowers there are several very small bracts covered with silky hairs. The flower is about $\frac{1}{2}$ inch long; the colour is chiefly due to the standard. The calyx-tube is short and has five narrow pointed hairy teeth; the lowest tooth is much longer than the others. The wing-petals are longer than the keel; the keel-petals are firmly joined along the bottom of the keel, and the claws of the four petals are joined to the stamen-trough. The standard is free, as is also the uppermost stamen. All the anthers are alike in size and position. The flower contains abundant honey, as can be ascertained by a very simple experiment; it has been called "Meadow Honeysuckle." Red Clover is visited by bees (chiefly humble-bees) and butterflies (e.g. "Clouded Yellow"); the tube is rather too long for the shorter-tongued bees (e.g. hive-bees). The stamens shed the pollen before the stigma is ready to receive pollen. The ovary is small and rounded, the style long; the pod contains only one seed as a rule, and the top generally comes off like a lid. The calyx persists around the pod and its five teeth spread out; the corolla withers, but remains on the plant instead of falling off.

249. Scarlet Runner (*Phaseolus multiflorus*).—We have already examined the seed and seedling of this well-known plant (Art. 89). The ease with which one can obtain vigorous young plants from seed makes the Scarlet Runner a very convenient plant in which to study the process of climbing by means of a twining stem.

Grow a seedling in a pot until the upper part of the shoot hangs over horizontally for a few inches. Tie the lower part of the stem to a stick placed in the soil, set the pot on a sheet of paper and record the position of the tip of the shoot. This may be done in several ways:—(1) by drawing lines on the paper radiating from the centre of the pot, so as to show the direction in which the stem-tip points; (2) by using a plumb-line (a string with a weight tied at one end) and marking the spot on the paper below the stem-tip; (3) by fixing a sheet of glass over the plant and marking on it the position of the stem-tip. Whichever plan is used, record the time when each observation is made, and find out how long it takes for the stem-tip to swing round through a complete

circle. In which direction does the shoot revolve—with the hands of a clock* or in the opposite direction?



Fig. 74.—Twining Plants: I., *Convolvulus*; II., *Hop*.

We know that warmth hastens the rate of growth of plants: does it hasten the rate of revolution of a climbing stem? Compare the times taken by the same plant to make a complete revolution when kept first in a warm place and then in a cold place, or *vice versa*. At 33° C. a Runner plant revolved in 2 hours 20 minutes, while at 24° C. the plant took 3 hours 25 minutes to revolve.

Get several vigorously growing plants ready, each in its own pot.

(1) In one pot set a long stick in a vertical position near the plant. Note that the stem swings round and stops at the point where it touches the support, while its free end goes on revolving; in this way it finds a support and then goes on growing upwards.

* The terms "with the sun" and "against the sun" are sometimes used instead of "clockwise" and "anti-clockwise." The plant (placed between sun and observer) points successively to East, South, and West in revolving "with the sun"; this occurs in the Hop (Fig. 74, II.) and Honeysuckle. The plant points successively to West, South, and East in going "against the sun," i.e. in the anti-clockwise direction; this occurs in most climbers, e.g. Scarlet Runner, *Convolvulus*.

(2) Must the support be vertical? Try the effect of setting the stick in an inclined position, in one pot at 30° from the vertical, in another at 45° , and so on. The Runner, like most other twiners, cannot, as a rule, climb up a stick set at more than 45° from the vertical. The *Convolvulus* will twine around a horizontal stick.

(3) What happens if you remove the stick before the shoot has made any coils around it? If you do this carefully, you will see that the shoot springs forward, showing that it has been pressing against the stick; then it becomes straight and starts again to revolve.

(4) What happens if you remove the stick after the shoot has twined round it for a day or two? Notice that now the shoot keeps its spiral form and does not straighten itself out.

(5) What happens if a thick stick or other thick support is used instead of a thin one? Use a large flower-pot or a box for this experiment, and place in it, near the plant, a thick cylinder of wood or a tube of cardboard or paper; try supports of different thicknesses (diameters of 2, 4, 6, 8, 10 inches). The shoot will not twine around a thick support (about 4 inches diameter), evidently because the support is not curved strongly enough to enable the shoot to hold on while the growing free end swings round the support.

(6) In what part of the shoot does the twining take place? Cut off the uppermost part of a shoot, just above the youngest expanded leaf. The shoot still revolves, even though several of the upper "internodes" be removed. It will be found, however, that the *lowest* "internodes" will not twine round the stick; it is only the upper (younger) parts which revolve.

(7) Does the stem become twisted as it revolves? From the external appearance of the stem and from the positions of the leaves, it would seem that twisting does occur. The best method of observing this is to paint a line along the convex side of the stem and to watch what occurs during a revolution. The line is seen to run round the stem, so that at the middle of the revolution it is on the concave side, while at the end of the revolution it is again on the convex side. The explanation is that the growth of the stem is not equally

rapid all round; a wave of rapid growth passes round the revolving free part of the stem. It would appear that the revolving movement of twining plants is due to a response to the stimulus of gravity, for no twining occurs when these plants are rotated on a clinostat (see Art. 167). The painted line is, after a few revolutions round the support, seen to be twisted round the stem from left to right; the twist probably makes the stem stronger, just as a much-twisted rope is stiffer than a loosely-twisted rope.

(8) Will the Runner climb up a very *smooth* support? Use a piece of glass tubing instead of a stick; the plant will climb, provided the tube is not too thick, but the twisting of the stem will be much less than when a rough support is used.

(9) Will the Runner climb up a piece of string, tightly-stretched or slack? It will be very easy to devise experiments to answer this question.

Note the thinness of the stem, which is not nearly strong enough to stand erect. In seedlings notice that the first

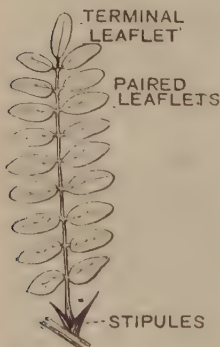


Fig. 75.—Leaf of Robinia Pseudacacia with Spiny Stipules.

“internode,” i.e. the portion of stem between the cotyledons and the pair of large simple foliage-leaves, grows erect, while the region above these first foliage leaves soon begins to bend over and to revolve. Note the compound leaves, each with three leaflets, which succeed the paired simple leaves; the stipules at the base of the main leaf-stalk, the very small stipule-like appendages at the bases of the individual leaflets, and the dark-green swollen leaf-base (*pulvinus*). The leaf shows sleep-movements, not nearly so marked as in Clover, but still fairly easy to observe, especially in young leaves. The three leaflets droop and place themselves more or less vertically, the two lower

leaflets approaching each other with their lower surfaces; at the same time the main leaf-stalk also moves in such a way as to bring the leaflets into the vertical position. Bend the stem so that the lower surface of a leaf is uppermost, and notice at the end of two or three days that the pulvinus

has bent until the leaf assumes its normal position, the individual leaflets adjusting themselves in a similar manner.

The drooping of leaflets in pairs can be seen very well in the "False Acacia" or "Locust Tree" (*Robinia*, Fig. 75); the evening appearance of the large compound leaves, with the numerous paired leaflets all placed vertically face to face, is very striking.

The general structure of the flower is like that of the Broad Bean, but the keel is coiled in two turns, enclosing the similarly coiled anthers and style (Fig. 76). The honey is secreted by two glands at the base of the ovary, and large bees alighting upon the wing petals press them downwards

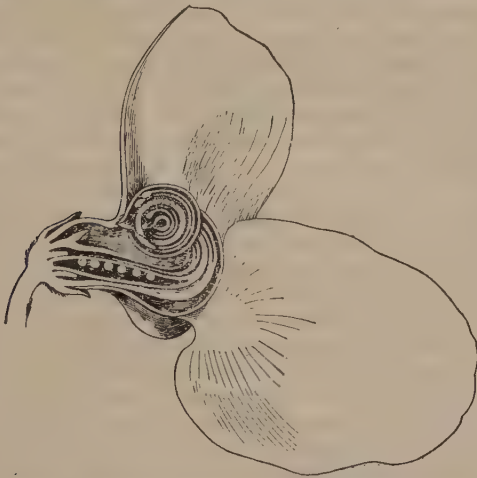


Fig. 76.—Longitudinal Section of Flower of Scarlet Runner.

and at the same time depress the keel to which they are attached. This causes the style to protrude and the hairs upon it sweep out pollen on to the base of the bee's proboscis. Before this happens, however, the latter has already touched the exposed stigma (which projects slightly from the tip of the keel), probably depositing pollen upon it from another flower. The exposure and retraction of the style may be repeated several times, and can easily be produced by pressing the

lateral petals downwards. This flower is so highly specialised for cross-pollination that if protected from bees by a gauze net it rarely sets seed

250. Common Gorse (*Ulex europaeus*), also called **Furze** and **Whin**, usually grows in large patches, often forming the chief or "dominant" plant in the vegetation of heaths. Though generally forming a shrub from 2 to 5 feet high, it sometimes grows into a strong erect tree, especially when in a sheltered situation; there are several isolated "Gorse trees," some nearly 20 feet high, for instance, on Southampton Common, the largest specimens being protected by railings.

There are three kinds of Gorse found in this country. The commonest and largest is that known to botanists as *Ulex europaeus*. It produces golden yellow flowers in great abundance in the spring and early summer; and a second crop of blossoms follows in autumn, lasting until nipped by the early frosts. In mild winters the last of the autumn flowers welcomes the first flower of the following spring.

Notice the stiff sharp spine in which each branch ends; the leaf below each branch is often also spiny. Remember the general rule that branches arise in the axils of leaves; this will help you to decide which of the outgrowths are branches and which are leaves. The branches, like the stem, are cylindrical and furrowed, while the leaves (1 to 2 ins. long) are flat. Both the leaves and (in the younger parts of the plant) the branches are green and more or less hairy. If you have a microscope, cut and examine sections of the stem and the branches, and also shavings of the epidermis, and notice that the stomates are found in the furrows; note also the thickness of the cuticle. Do you see how these structural features increase the amount of green tissue and so favour photosynthesis, while at the same time the rate of transpiration is kept down?

Why is the Gorse spiny? Two replies have been given to this question. It is held by some botanists that spines are the result of an environment of drought and exposure to winds; and it is quite true that Gorse grows most frequently in exposed places, and where the soil is shallow or porous or stony, and hence frequently dry. It is also true that many

plants which normally occur in deserts are spiny. Again, experiments have proved that many spiny plants when grown artificially in a damp atmosphere develop fewer spines or weaker spines, and sometimes no spines at all.

A second explanation is that spines are a protection against the attacks of sheep and other browsing animals. It is easy to see that spines, when once developed, furnish this protection; but it is difficult to understand how the desirability of being protected against browsing animals should actually cause the spines to be produced in the first instance. The correct view is probably that spines are a direct outcome of growth under conditions of exposure and drought, and, once formed, they may have become accentuated because of the protection which they afford.

Examine and compare plants found growing in different habitats. In moist and sheltered places Gorse is less spiny than usual. By growing a Gorse plant in moist air one gets branches on which there are no spines, and the leaves are broader and thinner than usual. It is a fair inference, from these facts, that the hardness and spiny character of the branches, as well as the narrowness of the leaves, are simply adaptations for diminishing transpiration. In what "habitats," i.e. in what kinds of locality, does Gorse grow most abundantly? With what other plants is it commonly associated? Do these associate-plants (Broom, Ling, Heaths, etc.) show any adaptations for reducing transpiration?

The two less abundant species of Gorse are smaller in size, and hence are often spoken of as dwarf Gorse. One of these (*Ulex Gallii*) is frequent on the hills in the west and north of England, as on the Malverns and the Pennines, also in Ireland. The other (*Ulex nanus*) is mainly confined to the south of England, often growing with the Common Gorse, from which it is easily distinguished by the smaller size of the plant and of all its parts. The two small species of Gorse are distinguished by the kind of primary spines they bear: in *Ulex nanus* they are weak and short, and in *Ulex Gallii* they are longer and rigid.

The flowers are yellow, slightly scented, about $\frac{3}{4}$ in. long, and are borne on the spines of last year's growth, each flower arising in the axil of a small leaf. The flower has a short stalk, and just below the calyx there are two small oval bracts,

one at each side. The calyx is dull yellow, covered outside with short blackish hairs, and divided nearly to the base into an upper lobe and a lower lobe; both lobes are triangular and concave, with pointed tips (the tip of the upper lobe often has 2 small teeth while that of the lower has 3 teeth). The bright yellow corolla consists of 5 petals which are easily separated from each other; the wings are longer than the keel, and the peg and socket connection between wings and keel is very distinct and easily made out. Both wing-petals and keel-petals are oblong, rounded at the free ends, and have distinct stalks; the keel-petals are joined by the interlocking of hairs which fringe the lower edge of their rounded portions. The filaments of the 10 stamens are all joined to form a tube. The stamens usually show a peculiar arrangement, the filaments being long and short alternately; the anthers of the long stamens are attached to the filament by the base, while the anthers of the short stamens are versatile, *i.e.* the filament is fixed to the middle of the anther so that the latter can easily be moved about. The ovary is green and covered with silky hairs; the style is long and curved.

It is interesting to watch bees visiting the newly-opened flower, or to imitate the bee's action by pressing down the keel. The flower "explodes"; the stamens and style, which are coiled up within the keel, suddenly fly out when the keel is pushed down, so that the bee is dusted with pollen and the stigma also comes against the bee's body. The bursting-open of the flower is due largely to the fact that the keel-petals are pressed together above as well as below by their edges, so that the coiled stamens and style are confined under pressure. The flower can only be properly visited once by a bee; the stamens and style do not go back into the keel, and the wings and keel-petals remain separate.

The pods in all three species of Gorse ripen during the summer only: pods formed from autumn flowers remain on the bushes in a resting condition throughout the whole of the winter. Many other autumn-flowering plants, such as the Autumn Crocus (*Colchicum*) and the Ivy, have the same peculiarity.

Examine fruits (pods) of different ages; note the blackness and hardness of the ripe pod. Why are the two

"valves" of an opened pod twisted? Have you ever stood beside Gorse-bushes on a warm dry day and heard the curious crackling noise due to the bursting of the pods? It is easy, if you watch carefully, to see the pods bursting and the two valves curling up, so as to fling out the seeds. On sunny days in summer ripe pods may be heard bursting with an audible "pop"; and the force of the explosion is sufficient to open the two valves of the pod and scatter the seeds a few feet away from the parent plant. This scattering of seeds is of course very useful to plants, but the distance to which the seeds are scattered is often exaggerated. It is a common idea, for instance, that wind-borne seeds (such as those of the Sycamore) may be scattered for miles; but a few hundred yards is a more correct estimate. Do not rest content with reading about the explosive discharge of the seeds in Gorse: make observations for yourself.*

Collect and sow Gorse seeds, or search for the seedlings in the neighbourhood of the bushes. The cotyledons come above ground and grow into fairly large oval green leaves. What do you notice about the earliest foliage-leaves, which come after the cotyledons? How do they differ from the later leaves? In what members of the Bean family are *all* the foliage-leaves like those of the young Gorse seedling? The young Gorse seedling has no spines: it has two simple seed-leaves, and a number of trifoliate leaves. In the older seedling a gradual transition may be traced from these trifoliate leaves, through simple linear leaves, to mature spiny leaves. The trifoliate leaves of the seedling are held to indicate a relationship with certain other plants with trifoliate leaves, such as Broom, Laburnum, and even Clover.

Grow young Gorse plants in moist air; set the pot of seedlings in a shallow dish containing water and cover with a bell-jar, tilting the latter so as to allow the young plants to have fresh air. How do the young plants grown under these conditions differ from plants growing on heaths or in other exposed places or in sandy soil? Make notes (with sketches) of all your observations, adding the inferences you draw

* The pods burst and fling out the seeds in several other plants of the Bean family, *e.g.* Laburnum, Vetches, Broom.

regarding the adaptations of the Gorse plant to its mode of life.

It is not generally known that furze is grown in certain localities as fodder for cattle. In its natural state the plant appears to be most unpromising food for any kind of animal, but the spineless seedlings, as well as the young shoots of the mature plant, are greedily eaten by horses and cattle, who find the furze as palatable as it is nutritious. The older shoots, however, have to be chopped and bruised to destroy the spines, and this is now done by machinery.

251. Laburnum (*Cytisus laburnum*) is a native of central Europe; it was introduced into England about 1600. It forms a small tree, rarely over twenty feet high.

Note that the spreading main branches bend over and droop at the tips; from the upper side of the bend arise erect long shoots which later also droop, so that the tree has typically a fountain-like habit. The bark is very characteristic; it remains smooth for many years, but later on transverse furrows are formed on the trunk and large scales of bark come off. Each leaf has a long main stalk carrying three short-stalked pointed leaflets which have entire edges and a silky lower surface; there are long slender stipules which soon wither, but usually do not fall off.

The resting-buds are pointed and covered with silky scales, each usually showing a small three-lobed tip (undeveloped leaflets). Most of the buds grow into dwarf shoots which grow very slowly and bear crowded leaves.

The flowers, which appear in May, are carried in long hanging racemes. Each flower is stalked and projects horizontally, the stalk (when the flower is young) twisting round so as to bring the flower into the right position, i.e. with the keel downwards and the standard upwards. The calyx and corolla resemble those of Gorse, and the stamens are all joined by their filaments; the anthers are alternately large and small, the style is long and curved. The flowers are visited chiefly by bees; the nectary is a swelling at the base of the stamen-tube, and there are two dark streaks (honey-guides) on the standard which lead to the nectary. Note the ring of hairs at the top of the style in the young flower; these hairs prevent the pollen of the flower's own anthers from touching the stigma, but after the style has grown right to the tip of the keel these hairs wither and the

stigma is now exposed so as to receive pollen from a visiting bee.

The ripe pod is long, thin, brittle; it contains from three to eight brown or nearly black globular seeds which are poisonous. The cotyledons are carried up and turn green; even the earliest foliage-leaves have three leaflets.

Laburnum is closely allied to Gorse and also to the Broom (*Cytisus scoparius*). The latter grows chiefly on commons and heaths, in sandy or gravelly soil, and is easily recognised by its numerous slender green angular branches and small leaves. The structure of the Broom flower resembles that of Gorse and Laburnum, but the style is longer and is tightly coiled up, as are also the long stamens. The flower "explodes" violently when the keel is pressed down. The mechanism is fairly easy to make out, either by pushing the keel down or, better, by carefully watching what happens when a bee visits the flower.

†252. **The Bean Family** is one of the largest, and also one of the most useful, among flowering plants. The family as a whole is characterised by the fruit being, with rare exceptions, a pod (legume)—whence its name Leguminosae. In the great majority of the species forming the sub-family Papilionaceae * the flower has the same general structure as that of the Broad Bean. There are two other sub-families not represented in Britain; one of those includes the Acacias and the Sensitive Plant (*Mimosa*). The family includes trees, shrubs, creeping plants, climbing plants, erect herbs, annuals, and perennials; the leaves vary greatly in form, etc. The Papilionaceae are easily recognised by their flowers. Examine all the plants of this type that you find growing wild or in cultivation.

Here is a list of a few common plants to study, making notes and sketches of your observations: Robinia ("False Acacia"), Wistaria, Broom, Kidney Bean, Eating Pea, Lupin, Bird's-foot Trefoil, Rest-harrow, Yellow Vetchling, Dyer's-weed, Petty Whin, Lady's-fingers, Sainfoin, Lucerne, Hedysarum ("French Honeysuckle").

Notice any differences in the calyx (are the lobes equal or unequal in length, smooth or hairy, etc.?); the corolla (how are the wings jointed with the keel? How much union is there between the two keel-petals?); the stamens (is the posterior stamen joined with the others so as to form a complete stamen-tube, or is it free? Are the filaments equal or unequal in length?); the pistil (length of style, its position with the keel, presence or absence of hairs). In each case sketch all the parts carefully (sketch the separated parts and a longitudinal section of the flower), and find out what happens when the keel is pressed down; if possible, watch bees at work on the flowers. The following notes on the chief types of **flower-mechanism** may be useful:—

(a) Stamens and stigma emerge from keel when it is depressed, and

* So named from the somewhat fanciful resemblance of the corolla to the wings of a butterfly (*papilio*).

return inside it again when the bee flies away; the same flower may therefore be visited several times: Clover, Sainfoin, Laburnum, etc.

(b) Keel-petals joined above as well as below, leaving a small opening at the tip; pollen shed into upper end of keel before flower opens; five of the stamens have filaments thickened below the anthers, and the piston thus formed pushes out some of the pollen each time the keel is depressed: Bird's-foot Trefoil (*Lotus*). The other five stamens are shorter and shrivel up after they have shed the pollen, which is carried by the long stamens (those with thickened ends) into the tip of the keel. A somewhat similar mechanism is found in the Lupin and in Lady's-fingers (*Anthyllis*).

(c) Upper edges of keel-petals at first joined, and pollen forced out at tip, as in *b*, but later on the keel splits open, and stamens and stigma emerge as in *a*: Rest-harrow (no honey in flower, therefore stamens all united).

(d) Like Broad Bean, with tuft of hairs on the style which sweeps the pollen out of the keel when the latter is depressed: most Vetches and Peas.

(e) Mechanism as in *d*, but stamens and style long and coiled up within a coiled keel: Kidney Bean, Scarlet Runner.

(f) Stamens and style tightly held, more or less coiled up, in the keel under tension, and springing out violently when keel is depressed: Gorse, Broom, Petty Whin (*Genista anglica*), Dyer's-weed (*G. tinctoria*), Lucerne and other Medicks (*Medicago*).

†253. **Leguminous Root-Nodules.**—It has been known for many centuries that crops of Clover, Lupin, Beans, or other leguminous plants actually enrich the soil in which they are grown. For this reason leguminous crops are often grown as "green manure" and ploughed into the soil. This fact is mentioned in Vergil's *Georgics*, but the explanation of it was only arrived at a few years ago.

It has long been known that the roots of Leguminosae often bear peculiar swellings, which in some cases (e.g. Broad Bean) are as large as peas. Various observers have written about them, and various views have been held regarding their mode of formation and their biology. Apparently the nodule begins as a swelling of the cortex of the main root or a rootlet, and at first the cells contain only Fungus-threads, which enter by means of the root-hairs. The nodule is evidently produced as the result of the entrance of the Fungus from outside, the Fungus setting up a stimulus to active growth of the cortex-cells. Later, the nodule becomes lobed and its outer cells become flattened, forming a sheath which contains vascular bundles. The Fungus-threads in the cells of the nodule branch profusely and give off numerous buds, as in the growth of the Yeast-plant; these minute bodies resemble Bacteria, and have been called "bacteroids." In annuals the nodules become emptied as the seeds ripen. Analyses show that the nodules are very rich in nitrogenous substances, also in potash and phosphorus, and they seem to develop best in soils which are poor in nitrogen-compounds. The nodules do not develop in plants grown in garden or field soil which has been heated so as to kill any

organisms present in it. On the other hand, they grow on roots of plants which have been germinated in garden soil and then placed in culture solution.

There seems little doubt that the Fungus lives in **symbiosis**—i.e. a mutually beneficial partnership—with the roots of the plant, and it apparently fixes the free nitrogen of the air present in the soil, just as some of the soil Bacteria do. The “bacteroids” budded off by the Fungus-threads are no doubt widely distributed in the soil, ready to germinate and send threads into the roots of Bean and other Leguminosae. The “bacteroids” supply the leguminous plant with nitrates (made by them from free nitrogen), while they are supplied with sugar manufactured by the host-plant. The case is evidently one of modified parasitism on the part of the Fungus, which sets up active growth in the root of the host-plant, but is kept in check and used by the host-plant to aid in its nutrition. This peculiar symbiosis between the “bacteroid”-forming Fungus and the roots of leguminous plants explains why the latter can flourish in soil containing little combined nitrogen and actually leave the soil rich in nitrogen-compounds after they have grown in it.

Some striking results have been obtained recently by Professor Bottomley, who has taken a leading part in the investigation of nitrogen-fixing organisms. For instance, two lots of Tare (*Vicia sativa*) seeds were taken. One lot was inoculated with nodule-bacteria and planted in sterilised sand to which the requisite potash and phosphorus salts was added. The untreated seeds were sown in sand containing nitrate of soda in addition to potash and phosphate. The seeds were sown in May; in July the Tares supplied with nitrate of soda yielded 1·9% of nitrogen, while the inoculated Tares gave 3% of nitrogen. Three experimental field-plots of Tares gave the following results in September:—(1) No nitrogenous manure used, 3·41% nitrogen; (2) nitrate of soda used, 3·75% nitrogen; (3) inoculated seeds, 4·04% nitrogen. In the case of field-crops the results are less striking, because fertile farm-soil always contains nitrogen-fixing Bacteria.

Professor Bottomley's work has led to a still more important result: plants other than Leguminosae can be inoculated with nitrogen-fixing Bacteria. Tomatoes have been made to yield a greatly increased crop by this means; the Bacteria were first cultivated in Tomato-juice. In Wheat the Bacteria can be induced to establish themselves in the rind (*cortex*) of the roots, though no nodules are formed.

Further information regarding the work of soil-Bacteria is given in *Plant Biology*, Chap. III. (“Roots and their Work”) and Chap. X. (“Biology of the Soil”).

QUESTIONS ON CHAPTER VII.

1. Describe the leaf of a Sweet Pea, with a careful sketch. Why is the stem of the Sweet Pea “winged”?

2. Describe the appearance of (1) a young Sweet Pea tendril before it has met with a support, (2) a tendril which has just caught a support,

(3) the same at a later stage, (4) an old tendril which has not grasped any support.

3. Describe, from your own observations and experiments, how a tendril acts.

4. Describe the vegetative parts (shoot and root) of the Everlasting Pea, and compare it throughout with the ordinary Sweet Pea.

5. Describe, with sketches, the flower of a Sweet Pea and its method of pollination.

6. Describe a common Vetch (*Vicia*) and compare it (as to shoot, leaves, flowers) with Sweet Pea and with Broad Bean.

7. Why is the Broad Bean placed with the Vetch (*Vicia*) genus, and not with other "Beans," *e.g.* French Bean or Scarlet Runner?

8. Describe the mode of growth of White Clover and compare it with that of Red Clover, pointing out how the vegetative organs of each adapt it to its surroundings.

9. Describe the sleep-movements of a Clover leaf as they occur in nature, and explain their causes and their utility. Give an account of experiments you have yourself made on these movements.

10. Compare the habit, habitat, leaf-structure, and leaf-movements of Clover and Wood Sorrel.

11. Describe and compare the flowers of Red Clover and White Clover, pointing out any differences in structure and mode of pollination.

12. Describe the way in which the Scarlet Runner climbs, and compare its climbing with that of Sweet Pea or Garden Pea.

13. Can you explain why a Scarlet Runner can only climb vertical or inclined supports, while a Sweet Pea can climb round even horizontal supports?

14. Describe the flower-structure and pollination-mechanism of a Scarlet Runner, with sketches.

15. How can you cause a Sweet Pea plant, or a cut branch, to go on flowering for a longer time than it would if left alone?

16. Sketch part of a Gorse plant, marking clearly which structures are leaves and which are stems. How are these organs distinguished?

17. Point out the structural features by which a Gorse plant is adapted to its usual habitat. What other plants are often found growing along with Gorse?

18. Describe observations and experiments which show that the peculiar features of the Gorse plant are adaptations for enduring drought.

19. Describe the seedling of Gorse, and discuss its structure and its relation to the structure of the mature plant.

20. Describe the structure of the Gorse flower. What happens when a bee alights on the flower? How often can a Gorse flower be visited by bees?

21. Describe the appearance of a Laburnum tree (1) in winter, (2) in spring, (3) in late summer or in autumn.

22. Describe the inflorescence of Laburnum, and compare it with the inflorescences of the other plants of the Bean family which you have studied.

23. In what respect does the nutrition of plants of the Bean family differ from that of most flowering-plants?

CHAPTER VIII.

LITTLE CELANDINE, BUTTERCUPS, WATER CROWFOOT, MARSH MARIGOLD.

254. Little Celandine (*Ranunculus ficaria*).—This familiar plant, easily recognised by its glossy heart-shaped leaves and its bright-yellow star-like flowers, grows chiefly in moist places, whether open or shaded.

Dig up entire plants and notice that there is no tap-root and that some of the roots are long, thin, and branched, while others are short, thick, swollen, and unbranched. Do the swollen roots contain reserve-food? How do the two kinds of roots differ in function? Cut across a swollen root and test with iodine solution: is starch present? Look for young shoots early in February, before the flowers have appeared, and note that above the swollen roots the young shoot has given off a number of ordinary roots; the latter serve for absorbing water and salts, while the growth of the shoot takes place at the expense of the food stored in the thick (often club-shaped) *root-tubers*. Note the large membranous sheathing scales (how many?) which protect the young shoot. Try to find earlier stages, with the young shoot still enclosed in its sheathing scales, before the leaves and the slender roots have grown out; when were the *tuberous* roots formed?

Examine plants in different stages of growth and at different times of the year, keep some under observation in pots or boxes, and make out as much as possible of their life-history. How do the root-tubers change as the leaves grow larger and the flowers appear? Note that the leaves are stalked, arise from the stem in opposite pairs (as a rule), and that the base of the stalk is broad and sheathing.

Examine the flowers (February to May), each on a stalk arising in a leaf-axil. In most cases the flower has three green sepals, then an outer series (whorl) of three petals alternating with the sepals, then an inner series of five petals; when there are more than eight petals, the extra petals lie within the normal inner series of five (compare with flower of Buttercup). Each petal has a small scale-like nectary at the base of its inner (upper) surface: why is this surface bright yellow and shiny, while the outer (lower) surface of each petal is dull and dark-coloured? What difference is observed if you visit the flowers on fine sunny days and on dull wet days? What advantages does the flower gain by closing in bad weather (wet, cold, or overcast)? In what kind of weather are most insects seen on the wing, visiting flowers? Note the numerous stamens, which ripen successively towards the centre of the flower, and the numerous carpels, which are not ready for pollination (*i.e.* the stigmas do not become expanded and sticky) until most of the anthers have opened (what is the advantage in this arrangement?). Examine the carpels carefully, noting the small stigma on each, and cut and sketch a longitudinal section of the flower.

The flowers are visited by various insects, the pollen being quite accessible and the honey only slightly hidden, so that flies as well as bees and wasps help in pollination. After pollination the flower-stalk curls over while the fruits are ripening. What other changes occur in an old flower, after it has been pollinated, or at least has had its chance of pollination? How do the petals change in colour, and why do they lose their power of closing up? It might be suggested that the bleaching of the old petals saves the time of intelligent insects, *e.g.* bees, by showing them that the flower is no longer worth visiting.

The fruits (akenes, nearly globular) are ripe about June. Examine an akene, peel off the coat, cut sections, and note the small embryo at one end of the seed, the bulk of which is occupied by endosperm; the embryo is peculiar in having only one cotyledon instead of two. Sow ripe seeds and study the seedlings; they take rather a long time to germinate.

You will generally find that plants growing in deeply shaded places—in woods or under dense hedges—produce

few fruits (why?), but to atone for this the plants produce small tuberous bodies (bulbils) in the axils of the leaves (note that shaded plants have longer stems and are less compact than those growing well exposed to light). Each bulbil contains starch and has a resting-bud; the bulbils eventually become detached and give rise to new plants. The shoots die down soon after the fruits have ripened, food being stored for the following spring in the tuberous roots and the bulbils, which are "hibernating" organs.

255. Buttercups (Fig. 77) belong to the same genus (*Ranunculus*) as the Little Celandine. They differ from it in having lobed (often deeply divided) leaves, five sepals, and five petals.

In a Buttercup flower note the five green sepals; the five petals alternating with these, each with a honey-scale at the base; the numerous stamens; the numerous carpels, each having a small thickened or hook-like stigma. Each of

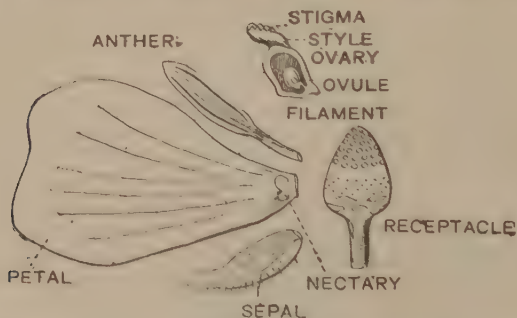


Fig. 77.—The Parts of a Buttercup Flower.

The points of insertion of the different parts are diagrammatically represented on the receptacle.

these parts is inserted independently on the receptacle, which is merely the expanded knob-like end of the flower-stalk. There is no *cohesion*—i.e. the receptacle-tissue does not grow up and raise the members of a series of flower-leaves on a basal outgrowth (compare sepals and stamens of Bean); the carpels contain each a single ovule, attached to

the bottom of the ovary. The flower is shallow, accessible to all kinds of insects, which visit it for the abundant pollen as well as for the honey (only slightly concealed by the outer stamens). Examine flowers of different ages; the outer stamens have shed their pollen (the anthers open at the sides), while the inner ones are still bent over the carpels, covering the stigmas, which are not exposed until most of the stamens have moved outwards and have set the pollen free to be carried away by insects. The "male stage" and the "female stage" thus overlap for some time, during which self-pollination is possible, either because the innermost stamens touch the stigmas or by means of small insects crawling over the flowers.

The Bulbous Buttercup (*R. bulbosus*) is easily distinguished when in flower; the sepals curve outwards and downwards. The stem is swollen at the base, forming a kind of corm; the lower leaves are broad and many-lobed, the upper ones have only a few narrow lobes. The Creeping Buttercup (*R. repens*) has long creeping branches (runners) which grow along the soil and at the "nodes" send roots downwards and shoots upwards. The Meadow Buttercup (*R. acris*) has neither runners nor a thickened stem-base, its flower-stalks are not grooved (as are those of the other two species), and it is the tallest of British Buttercups, being sometimes more than a yard in height; the sepals are, like those of *R. repens*, spreading, not reflexed as in *R. bulbosus*.

The three commonest species of Buttercup agree in many respects—e.g. in having five sepals and five petals, etc.—but are distinguished by the following, amongst other, characters:—

	Bulbous Buttercup (<i>Ranunculus bulbosus</i>)	Meadow Buttercup (<i>Ranunculus acris</i>)	Creeping Buttercup (<i>Ranunculus repens</i>)
Stem	Swollen at base, for storage of food	Not swollen at base; no runners	Gives off runners, which root at nodes, producing new plants
Flower-stalk	Furrowed	Rounded	Furrowed
Sepals	Reflexed, i.e. bent downwards	Spreading	Spreading

The ordinary Buttercups are sometimes called "Crowfoots" from the shape of the leaves in most species, but the two "Spearworts,"

which grow in marshy places, are easily distinguished by their long and narrow tapering leaves. Like ordinary Buttercups they have yellow flowers. The Lesser Spearwort (*R. flammula*) is the more widely distributed; it is rarely over 1 foot high, its lower leaves are stalked, and its flowers about $\frac{1}{2}$ in. in diameter. The Greater Spearwort (*R. lingua*) is 2 to 3 feet high, its leaves are all sessile, and its flowers about 2 ins. in diameter.

256. Water Crowfoot (Fig. 78).—Under this name are comprised various forms of Buttercup or Crowfoot which live in marshes or streams and have white flowers.

The Water Crowfoots are very variable and the varieties are connected by intermediate forms, so that systematic botanists are not agreed as to the number of species that can be distinguished. Those which grow in fast streams have most or all of their leaves submerged and divided into numerous fine threads—the form best adapted to resist tearing by the running water, besides increasing the surface for absorption of water with dissolved salts and gases. The submerged leaves have chloroplasts in their epidermis, which bears no cuticle, so that water containing dissolved salts and gases can pass in freely. Since the submerged parts get their salts, oxygen, and carbon dioxide directly from the water, there are no stomates, nor does the stem contain many wood-vessels, and the roots serve chiefly to fix the plant to the bottom, having few or no root-hairs, since root-absorption is not required.



Fig. 78.—Part of a Water Crowfoot, showing a floating leaf and two submerged leaves.

As we have seen, a land plant requires to have its stem and leaves strengthened by hard tissue, arranged so as to resist the strains caused by weight and by wind. The stems of submerged water plants are slender (all about the same thickness) and weak, with long “internodes” (partly owing to the light being largely absorbed by the water). In a water plant the weight is, of course, supported by the water, and the only strain to which fixed submerged plants are subject is a pulling-strain due to movement of the water, especially in fast streams. For these reasons there is little

or no special hard tissue outside of the vascular bundles, and the latter are placed in the centre of the submerged stem, as in the *root* of a land plant.

In those forms which grow in slow streams, ditches, or ponds, there are usually floating leaves (on the surface of the water) as well as submerged leaves; the former are rounded or lobed, not divided, and bear stomates on their upper surface, which is covered with cuticle or wax so as to prevent wetting. These floating leaves have the same structure as those of land plants, but the air-spaces are very large and are continuous with air-passages running down the leaf-stalk to the submerged stem and roots. The air-spaces enable the plant to float upright, but they also convey air to the lower parts growing in deep water or in mud, where little or no oxygen is present for respiration.

Since a submerged plant gets water, salts, and carbon dioxide so easily, and lives in very favourable conditions generally, it grows rapidly, branches freely, and reproduces itself largely by vegetative means, *e.g.* by the decay of the older parts setting the branches free, or by branches breaking off.

In forms which grow in shallow streams or pools, in marshes and muddy places, all or most of the leaves are of the entire, rounded or lobed, "floating" type. We thus get every transition from plants with all or most of the leaves submerged and dissected, to plants with all the leaves broad and either floating on the water or raised above it. The intermediate forms are "amphibious"; when the stream or pond dries up, they grow quite well in the mud, bearing only aerial leaves and no finely divided ones. On the other hand, if flooded or transplanted into water in an aquarium, they will grow and produce only the divided submerged leaves. Experiments of this kind should be made: sow in damp soil the seeds of submerged forms, sow in water those of mud-inhabiting forms.

In all cases the flowers are carried above the surface of the water; they resemble the flowers of ordinary Buttercups in general structure. The flower-buds are developed below the surface, but do not open until they reach the air.

257. Marsh Marigold or Kingcup (*Caltha palustris*).—This plant, which grows in low-lying meadows, marshes,

banks of streams, ponds, ditches, and other wet places, has a tufted habit.

The thick perennial rhizome bears annual shoots, about a foot long, which either grow erect or creep and root at intervals. Most of the leaves arise from the base of the stem and are long-stalked; the sheathing leaf-base has large membranous stipules which enclose the young buds. The upper leaves, carried on the flowering branches, are smaller than the lower ("radical") leaves and have very short stalks. Cut across stems and leaf-stalks, noting their hollow structure. Blow through a leaf, with (1) the stalk, (2) the blade, dipping into water; plunge a leaf into hot water.

Note the large flowers (often 2 inches in diameter), with golden-yellow flower-leaves (*sepals*),* numerous stamens, and from 5 to 10 carpels. Note the resemblance of each carpel to the single carpel ("pistil") of Bean or Gorse. Open up a carpel and note the arrangement of the seeds: how many rows are there, and on what side of the carpel, inner (towards centre of flower) or outer, are they carried? When ripe it becomes a dry fruit (follicle) which splits open along the seed-bearing inner edge; the seeds are gradually shaken out as the wind rocks the fruit to and fro.

† **258. Water and Marsh Plants.**—Many of the adaptive characters of water plants are illustrated by the different forms of Water Crowfoot, and have already been mentioned. Submerged plants are subject to less extremes of temperature than land plants, since, owing to its high specific and latent heats, water takes longer to be heated and longer to cool than soil does. The mechanical conditions under which submerged plants live have already been referred to.

As regards nutrition, water plants are well supplied with carbon dioxide, since this gas dissolves very readily in water: water at 15°C. dissolves about its own volume of this gas, which is present in such a small proportion in air. On the other hand, the proportion of oxygen dissolved in water (it need hardly be pointed out that water plants do *not* get their oxygen for respiration by the splitting-up of water) is much smaller than that present in the air. In the lower parts of a fixed water plant, or a marsh plant (*i.e.* a plant having its leaves mostly, or all, in the air, but its roots and shoot-bases in water or mud), there is a poor supply of oxygen. The water or mud at the bottom is poor in oxygen as compared with the surface-water: still or sluggish water

* How do these apparent petals differ from the petals of Celandine and Buttercup? (See Art. 259.) Honey is produced at the bases of the carpels; the flowers are visited by beetles (chiefly *Meligethes*, Art. 212), flies, bees, etc.

contains less oxygen than running water. The air-spaces found in the leaves, leaf-stalks, stems, and roots of water plants serve to convey air to the badly aerated parts; in submerged plants they serve also for support, but their primary importance for aeration is shown by their large development in marsh plants.

Another point to remember is that water absorbs light to such an extent that submerged plants are growing under the same light-conditions as shaded land plants. This seems to account partly at least for the long "internodes" of the stem, the absence of palisade tissue in the leaves, and some other features.

More than half of the British species of the Buttercup family live in water or in marshy places; the name *Ranunculus* ("little frog") refers to the moisture-loving character of many *Ranunculaceae*. The types we have studied show a gradual transition from land plants to water plants. Can you arrange the common Buttercups and the other plants given in this chapter so as to illustrate this gradual transition, from your own observations? Note the structural features which mark the transition: the air-spaces in Little Celandine and Marsh Marigold (the latter a more decidedly moisture-loving plant than the former), the presence of abundant stomates on the upper side of the leaf in these plants, etc.

How can these features be explained? Everything we know of water- and marsh-inhabiting Flowering Plants shows that these have descended from land plants. They probably began by growing in damp places, like some Buttercups; then became adapted to more permanently moist places, acquiring large air-spaces for better aeration and having stomates as abundantly on upper leaf-surface as on lower, or more so, since there was no need to check transpiration—this stage is illustrated by Little Celandine.* Then, driven by the struggle for existence, the plants came to grow in marshes or standing waters and developed still more pronounced marsh characters, and finally took to growing in water, with the leaves submerged or floating.

The commoner water plants, with submerged or floating leaves, or both kinds, which grow in ponds and streams include Quillwort (*Isoetes*), Canadian Water-weed (*Elodea* or *Anacharis*), Pondweeds (*Potamogeton*, *P. natans* with stalked oblong leaves being the commonest species), Frog-bit (*Hydrocharis*), Water Soldier (*Stratiotes*, only in East England), Duckweeds (*Lemna*), White and Yellow Water-lilies (*Nymphaea*, *Nuphar*), Horned Water-weed (*Ceratophyllum*), Water Crowfoots, Water Starworts (*Callitriche*), Water Milfoil (*Myriophyllum*), Water Violet (*Hottonia*), Bladderwort (*Utricularia*), Shore-weed (*Littorella*), Water Lobelia (*Lobelia dortmanna*). For descriptions of these plants see a British Flora, e.g. Hooker's *Student's Flora*.

* It is interesting to note that the stomates of bifacial leaves are, as a rule, confined to the lower side in evergreen leaves; found on both sides (more abundantly on lower side) in most British plants; more abundant on upper side in many marsh plants; confined to upper side of floating leaves and of Grass leaves. In cylindrical leaves—e.g. Onion—they are evenly scattered, and this is also the case with most needle-like leaves—e.g. Pines.

Between submerged water plants, moisture-loving plants, and ordinary land plants there is every stage of transition. We can, however, distinguish between truly aquatic plants and those characteristic of marshes and bogs.* The former are permanently submerged in water, whereas bogs and marshes occur where the substratum alternates between long periods of submergence and shorter periods of more or less complete drying-up. As we have seen, submerged water plants get oxygen and carbon dioxide, in addition to salts, from the water; hence they occur mainly in water which is moving, or at least often renewed. On the other hand, water plants with floating or with aerial leaves can grow in stagnant pools or ditches where there is little oxygen, and where organic acids and marsh gas are abundant. The same is true of marsh and bog plants, whose characteristic feature is that their lower parts, buried in the stagnant mud, are adapted to life in water, while their upper parts, exposed to the air, may resemble those of ordinary land plants or may have leaves adapted to withstand periods of drought. The reduced leaf-surface and thick cuticle of Rushes, Sedges, etc., which are characteristic of drought-resisting plants, are probably due to the fact that stagnant mud (especially in peat-bogs) contains acids produced by the decaying organic matter (humus), making it difficult for the plants to absorb water. But this is only one factor in the rather complex biology of marsh plants.

The commoner marsh plants, which grow on the margins of ponds and streams, or with their lower parts in water, but usually have all or most of their leaves above the water—not submerged or floating—include Pillwort (*Pilularia*), Horsetails (*Equisetum*), Sedges (*Carex*), Rushes (*Juncus*), Bulrushes (*Typha*), Bur-reeds (*Sparganium*), Water Plantain (*Alisma*), Arrowhead (*Sagittaria*), Flowering Rush (*Butomus*), Marsh Arrowgrass (*Triglochin palustre*), Yellow Iris, Marsh Orchis, Willows, Alder, Water Dock (*Rumex conglomeratus*, *R. hydrolapathum*), Water Pepper (*Polygonum hydropiper*) and other water-loving Polygonums (*P. amphibium*, *P. bistorta*, *P. persicaria*), Blinks (*Montia*), Ragged Robin, Water and Marsh Stitchworts (*Stellaria aquatica*, *S. uliginosa*), Water-cress (*Nasturtium*), Lady's-smock (*Cardamine*), Water Avens, Meadow-sweet, Golden Saxifrage, Purple Loosestrife (*Lythrum*), Willow-herbs (*Epilobium*), Water Purslane (*Peplis*), Mare's-tail (*Hippuris*), Marsh St. John's-wort (*Hypericum elodes*), Water Dropworts (*Oenanthe*), Wild Celery (*Apium*), Water Parsnips (*Sium*), Water Hemlock (*Cicuta*), Knotted Marshwort (*Helosciadium*), Marsh Pennywort (*Hydrocotyle*), Brook-weed (*Samolus*), Yellow Loosestrife (*Lysimachia vulgaris*), Moneywort or Creeping Jenny (*L. nummularia*), Water Forget-me-Not, Marsh Woundwort, Water Mint, Pennyroyal, Gipsy-wort, Water Speedwell (*Veronica anagallis*), Brooklime (*V. beccabunga*), Marsh Speedwell (*V. scutellata*), Red Rattle (*Pedicularis palustris*), Marsh Figwort (*Scrophularia aquatica*), Marsh Hawk's-beard (*Crepis paludosa*), Water Ragwort (*Senecio aquaticus*), Hemp Agrimony (*Eupatorium*), Bur Marigold (*Bidens cernua*), Marsh Cudweed (*Gnaphalium uliginosum*), Marsh Thistle (*Cnicus palustris*), etc.

* Bog plants are dealt with in Chapter XI.

†259. **The Buttercup Family.**—Examine flowers of other plants belonging to this family (Ranunculaceae). In Wood Anemone there are numerous carpels and stamens, then a series of white spreading leaves (do these bear nectaries?), and outside of these, a little below the receptacle itself, there is a series of green divided leaves. In Pasque-flower (*Anemone pulsatilla*), outside of the stamens we find a series of small honey-scales, then a series of large blue leaves which, together with the stamens, conceal the honey from short-tongued insects, e.g. flies. The Wood Anemone is visited by insects of all kinds for its pollen, but the Pasque-flower is visited chiefly by bees for honey; the former begins flowering in April, the latter about a month later, when more bees are on the wing. The Meadow Rue has numerous small flowers; the stigmas mature before the stamens, and outside of the latter there is a series of small leaves which soon fall off. The flowers are chiefly pollinated by the wind, though sometimes visited for pollen by insects. In Winter Aconite (January to March) and Christmas Rose (February to April) we find outside the stamens a series of small honey-tubes; here, as in Anemone, we find an outer ring of divided leaves (bracts) just below the flower. In Wild Clematis (July to August) there are no nectaries, and only one series of flower-leaves outside the stamens; it is a pollen-flower, like Wood Anemone. The comparison of these flowers suggests that most of them have not yet developed petals, whose attractive function is assumed by the coloured (petaloid) sepals, or that petals may have been derived from the outermost stamens, or that sepals may have evolved from foliage-leaves or bracts growing just below the flower. Perhaps the flowers of this family are still in course of evolution; at any rate, very few show the distinct sepals and petals of a "typical flower." "Sepals" are always present (primarily as a green protective envelope), and should the "petals" develop as honey-tubes or remain undeveloped the "sepals" usually become white or coloured when the flower opens, rarely remaining green (Wild Hellebore), so that it is at least convenient to limit the term "petals" in this family to the honey-leaves.

In the next flowers to be mentioned the "sepals" are petaloid, the "petals" bear curious nectaries, which can only be reached by long-tongued bees; the flowers open in summer, when bees are plentiful, are visited chiefly by humble-bees, and usually have the rich blue colour characteristic of so many "bee-flowers." In Columbine each petal bears at its base, on the outer side, a long tube (spur), at the end of which there is a nectary; the flower-stalk is curved, so that the flower hangs down, and the spurs are curved at the ends (this prevents the honey from dropping out, and the drooping of the flower protects pollen and honey from rain).

This type leads to others in which the flower is "irregular," and insects can only enter in one particular way. In Larkspur the large posterior sepal has a long spur at its base; into this project two processes from the two upper petals, which are pressed together so as to form a tube above and a solid mass (nectary) below, and the entrance to this elaborate honey-pocket is narrowed by the two side-petals (which act as "honey-guides") and by the stamens which move up

into the mouth of the opening in turns as they mature. In Monkshood the posterior sepal* forms a large hood covering the two posterior petals, each of which consists of a stalk carrying a nectary with a tube whose opening faces downwards. The humble-bee often bites through the petal-spurs of Columbine and the hood-sepal of Monkshood, but the thick double-walled spur of Larkspur seems to prevent this. These three flowers are fine examples of adaptation to a special insect-visitor; the pollen and honey are sheltered from rain, and the honey can only be reached by a large and long-tongued bee. All three (somewhat rare in the wild condition, but commonly grown in gardens) flower in summer, when humble-bees are most abundant. The limit of distribution of the Monkshoods (*Aconitum*) closely follows, and is just within, that of the humble-bee (*Bombus*).

† **260. Classification (Varieties, Species, Genera, Orders, Cohorts).**—The study of the Buttercup family affords a good opportunity to learn something of the principles involved in the classification of plants. The object of classification is to arrange plants in a scheme which shall as nearly as possible express their actual affinities or relationships by descent, *i.e.* by evolution from common ancestors. A really natural scheme of classification can never be more than an expression of our views concerning these “blood relationships,” but as our knowledge increases by further research the system becomes more and more a true reflection of the affinities of plants.

As is well known, there is a certain amount of variation among the offspring of all plants, though the general characters of the parents are handed down by heredity. Sometimes the variations are slight and “continuous,” *i.e.* connected by intermediate forms with one another, but they may be more marked and “discontinuous,” *i.e.* hardly, if at all, connected in this way. Formerly it was believed that the small continuous variations formed the material from which species arose by natural selection, but there is reason to regard the large discontinuous variations or “mutations” as being of much greater importance in evolution. The Water Crowfoots are mostly connected by intermediate forms and might almost be regarded as belonging to a single species, especially as they vary according to the conditions under which they grow.

When variations are less “fluctuating” or “discontinuous,” they become more or less fixed **varieties**. For instance, there are two common varieties of Meadow Buttercup (*Ranunculus acris*): in one the stem is densely hairy at the base, and the segments of the “radical” leaves overlap each other; in the other variety the stem is only slightly hairy, and the leaf-segments do not overlap. Many examples of varieties are found in cultivated plants. Varieties differ from each other in small and variable characters, chiefly affecting the vegetative organs, but sometimes in floral characters of slight importance—*e.g.* shape and colour of petals. **Species** differ in more

* There is a posterior or uppermost sepal in nearly all the families of Dicotyledons, the Bean Family (Papilionaceæ) forming the only important exception.

important characters of the vegetative organs, or of flowers and fruits, or of both. We have already studied the distinguishing characters of the commoner species of Buttercup. When the differences become still more pronounced and more constant we agree to recognise distinct **genera**, and a number of closely related genera constitute a **Natural Order**. Thus the Buttercups, Anemones, Marsh Marigolds, Aconites, Paeonies, and Larkspurs all belong to different genera of the Natural Order **Ranunculaceae**.

Natural Orders differ from one another in having different types of flowers and different arrangements of the flowers and leaves. Families or orders are grouped into **Cohorts**. The cohort **Ranales** includes, besides the Ranunculaceae, the Nymphaeaceae (Water-lily order), Magnoliaceae (Tulip-tree order), Berberidaceae (Barberry order), Myristicaceae (Nutmeg order), Lauraceae (Laurel order), and a few others. The cohorts of seed-plants fall into four great divisions—**Gymnosperms**, **Monocotyledons**, **Lower Dicotyledons** (*Archichlamydeae*), and **Higher Dicotyledons** (*Sympetalae*)—the three latter divisions forming the **Angiosperms**.

As you proceed with the work of classifying plants, you will realise that the boundaries between varieties and species, between species and genera, and so on, cannot be precisely and sharply defined; the same applies even to the boundary between the lowest plants and animals. This is, of course, just what we might expect from what we know about variation and evolution. Hence an absolutely natural system of classification can only be an ideal to be aimed at. The nearest approach to such a classification of Angiosperms is that of Engler and Prantl (adopted in *Plant Biology*, Appendix III.), which should be compared with the Bentham-Hooker arrangement given in British Floras.

QUESTIONS ON CHAPTER VIII.

1. How does the Little Celandine hibernate, and at the same time multiply apart from seed-production?
2. Describe, with sketch, the appearance of a Little Celandine plant when its leaves first appear (end of January or in February).
3. Describe the flower of Little Celandine and compare it with that of an ordinary Buttercup. What property has the Celandine flower that is not possessed by a Buttercup flower, and why?
4. Describe, from your own observations, the movements shown by the flower and the flower-stalk of Little Celandine.
5. Show how you would distinguish between the three commonest Buttercups. How do they differ as regards the situations in which they usually grow, and the time of year in which they flower most freely?

6. Describe the adaptations which the flowers of Celandine, Buttercups, and Water Crowfoot have for securing pollination. Which of these will be likely to receive most insect-visits, and why? Which will get fewest visitors, and why?

7. Describe a Water Crowfoot and compare it with an ordinary Buttercup.

8. Describe the adaptations shown by a water plant with floating leaves or-submerged leaves, or both, to its mode of life.

9. Why are aquatic Flowering Plants believed to have descended from land plants?

10. Describe and compare the leaves, flowers, fruits, and mode of life of Marsh Marigold and Little Celandine. Why are the yellow leaves of the flower of Marsh Marigold regarded as being sepals and not petals?

11. Describe the flowers and fruits of Clematis, and point out the resemblances and differences between this plant and a Buttercup. By what organs does Clematis climb? In what respects does Clematis differ from the other British members of the Buttercup family?

12. Describe the flowers of Larkspur and Monkshood, and compare them with a Buttercup flower.

13. What wild flowers have you found growing along the margins of lakes, ponds, and rivers? Distinguish those which grow with their stems (*a*) wholly in the air, (*b*) partly in air and partly in water, (*c*) wholly submerged. Show by sketches what you mean by the zones of vegetation along the water margin.

14. Write a list of any plants which you have found growing with their leaves submerged in water. How do such plants obtain the gases which they require for respiration and photosynthesis? Describe the surface structure of a leaf (*a*) in a land-plant, (*b*) in a water-plant.

CHAPTER IX.

DOG ROSE, STRAWBERRY, HAWTHORN, ROWAN.

261. Dog Rose (*Rosa canina*).—There are many species and varieties of Wild Roses in Britain, the Dog Rose being the commonest as well as the largest.

The plant has a woody “stock” which produces suckers; these are also given off by the roots in some cases. During the first year of growth each shoot usually grows erect to a height of three or four feet and does not branch; later on the shoot may branch freely and reach a length of ten feet or more in a single season.

How do the long arched shoots scramble over other plants in a hedge? Try to pull a branch away from the hedge: note how it resists your pull by clinging to its companion plants in the hedgerow. Sketch a piece of the shoot, showing the shape of the prickles and the direction in which they curve. Are the prickles deeply embedded in the stem, or can they be pushed off easily? Each prickle is evidently part of the rind or outer tissue of the stem. Are the prickles scattered evenly over the branch, or do they tend to be clustered at the “nodes” where the leaves come off? Do you see any advantage in this arrangement of the prickles?

How many leaflets are there on each leaf? Does the leaf bear any prickles? Sketch a leaf, showing the narrow pointed stipules which adhere to the base of the leaf-stalk; pull a leaf down and notice the bud, which is protected by the stipules.

Trace a side shoot down from its tip to the place where it springs from an older, leafless part; note the leaf-scars on this older part, which belongs to last year's growth. Trace

this two-year-old part back to where it in turn arises from an older stem with a darker surface; this three-year-old part is thicker and harder to cut.

Do all the shoots bear flowers? Do the flowers grow singly or in clusters? Are the flowers found in the thick parts of the hedge, or only at the top and along the sides, where there is plenty of air and sunlight? How does the arrangement seem advantageous with regard to (1) the pollination of the flowers, (2) the ripening of the fruits, (3) the dispersal of the fruits? Examine a flower (Fig. 79),

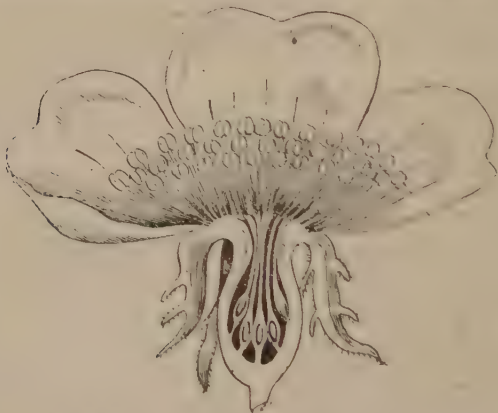


Fig. 79.—Longitudinal Section of Flower of Dog Rose.

noting the green urn-like tube from the edge of which arise the five green sepals, the five white or reddish petals, and the numerous stamens; the petals are attached by a narrow base, as in Buttercups, while the sepals have broad bases. Examine the sepals carefully, noting the appendages which fringe the edges; are all the sepals fringed on *both* sides, or are any of them fringed on one side only, or not fringed at all?

Examine a flower-bud and see whether the relative positions of the sepals throw light on the distribution of the fringes. The Dog Rose has no honey, but the flower is visited by various insects for pollen; a honeyless but otherwise insect-attracting flower is sometimes called a "pollen-flower," other examples being seen in Poppies, Rock-rose (not a true Rose),

St. John's Worts. Note the numerous styles, each with a slightly dilated stigma, which project a little from the mouth of the flower-tube. Cut a flower down through the middle of the tube and trace the styles down to the ovaries which are inserted all over the lower part of the tube. The stigmas become receptive practically at the same time that the anthers open, but insects generally alight on the stigmas first, and thus bring to them pollen from previously visited flowers.

Examine twigs showing various stages in the formation of the fruits ("hips"), noting that the sepals become bent downwards but do not fall off before the fruit ripens and turns red. Note the shape of the fruit (from what part of the flower is the red fleshy "hip" formed?), the narrow mouth of which is blocked with woolly material; on the rim of the urn notice the five scars where the sepals have fallen. Cut the "hip" in two longitudinally, noting its thick wall and the numerous seed-like bodies (really fruits, *akenes*, since each is formed from an ovary) within it, and the white threads (bundles) passing from the flower-stalk into the wall of the "hip." Why is one side of each akene curved and the other two sides flat? Note the slender thread (style) at the top of each akene, also the stiff brittle hairs covering the akenes and the inner surface of the "hip." The akenes are dispersed by birds, which are attracted by the bright colour of the fleshy "hip."

† Some of the commoner Wild Roses are easily identified. The Burnet Rose (*R. spinosissima*) is a small erect bushy plant (1 to 3 ft. high), with crowded prickles varying in size and shape, but mostly straight, and passing into mere bristles and glandular hairs; seven to nine small leaflets; flowers small, solitary; fruit nearly black; sepals persistent and erect on top of "hip." The Sweet Briar (*R. rubiginosa*) is more closely allied to Dog Rose, but its leaves have a pleasant smell when rubbed owing to an aromatic substance produced by numerous small reddish gland hairs on leaf-stalks and lower side of leaflets; the prickles are hooked but mixed with bristles and hairs; flowers usually solitary. The Field Rose (*R. arvensis*) has leaves and prickles as in Dog Rose, but is a more trailing plant; the flowers are white, scentless, in clusters (3 or 4); "hip" globular; sepals not fringed; styles united into a column which projects from mouth of "hip"; this species keeps on flowering later than the Dog Rose. The Downy Rose (*R. villosa*) is distinguished from the downy varieties of Dog Rose by the globular fruit, which bears small prickles; the stem-prickles are straight or only slightly curved, the leaflets downy on both sides.

262. Strawberry (*Fragaria vesca*).—The cultivated kinds should be examined as well as the wild form, which differs chiefly in the smaller size of the various parts.

Note the perennial rhizome, which is woody and scaly, giving off in early summer the numerous (rarely more than ten) creeping branches (runners). Each runner arises in the axil of a leaf on the rhizome, grows along the soil, and at intervals sends roots downwards and shoots upwards. The roots contract and become wrinkled, pulling into the soil the shoots, from whose bases more roots grow out. The flowering shoots are erect (3 to 6 ins.), covered with soft hairs; the basal leaves have long stalks with three leaflets with toothed edges, but the upper leaves are simpler and have short stalks or none.

The runners of the Strawberry not only enable the plant to spread over the soil and send up leafy and flowering shoots where there is plenty of air and light; they also serve for propagation apart from seeds, that is "vegetative" reproduction; since the slender scale-bearing part of the runner withers after the new shoots have grown up, the latter become free from the parent plant and form independent plants.

In the flowers note first the saucer-like receptacle (corresponding to the urn-like structure in the Rose flower) bearing at its edge five green sepals, on its upper side the five white petals and the numerous stamens, and on its lower side five small green leaves alternating with the sepals. The leaves below the sepals form the "epicalyx"; they represent the stipules of the sepals, which have grown together in pairs. In the centre of the flower arises a knob which bears the numerous small carpels, each with a short style and a small stigma; between the rim of the "saucer" and the central carpel-bearing knob there is a ring-like nectary or honey-disc.

The honey is only slightly concealed by the stamens, and the flowers are visited by flies as well as by larger and longer-tongued insects (bees, etc.). The stigmas become ready to receive pollen, *i.e.* reach their full size and become sticky, before the anthers of the flower open to shed the pollen, so that self-pollination is to some extent hindered and cross-pollination favoured; pollen may be brought to the flower in

its first ("female") stage from another flower (younger or older?). Compare the opposite condition seen in Buttercups; the flowers of the latter are *protandrous*, those of Strawberry *protogynous*, while in flowers like those of Roses the anthers and stigmas mature simultaneously (*homogamous* condition). In some cultivated varieties of Strawberry the lower part of the knob bears no carpels, and sometimes the flowers are unisexual, *i.e.* either have stamens or carpels, but not both in the same flower.

After fertilisation of the carpels, the central knob swells and becomes fleshy; the petals fall off, but all the other parts persist, even the withered stamens. The ripe carpels or "pips" (akenes) remain on the surface of the knob and are dispersed by birds which are attracted by the brightly coloured and fleshy mass, eat it and the "pips," and either drop the latter or pass them through their digestive canal.

Compare the fruits of Strawberry and Rose. In the Strawberry the receptacle is divided into a saucer-like part and a central knob, instead of being a deep urn with a narrow mouth, and the akenes are borne on the surface of the knob instead of being on the inside of a cup; in both cases, however, the fleshy part is formed from the receptacle, and it is instrumental in bringing about the dispersal of the akenes by birds.

Be careful not to confuse the true Wild Strawberry with the "Strawberry-leaved Potentilla," often also called "Barren Strawberry," which is a species of *Potentilla* resembling the Strawberry in having short tufted stems, silky hairs, three toothed leaflets, and white flowers, but the receptacle knob does not swell or become juicy, nor does the stem send out runners so freely as in the Strawberry. Besides the Barren Strawberry (*P. fragariastrum*), there are several other common species of *Potentilla*, differing from it in having yellow flowers. The Tormentil (*P. tormentilla*), so common on heaths, is easily known by its erect or slightly creeping stems, stalkless upper leaves, small flowers with (usually) four petals; it flowers all summer. The Creeping Cinquefoil (*P. reptans*) grows chiefly in hedges, flowering later in summer and in autumn, has long creeping stems, leaves all stalked and with five leaflets, and larger flowers with (usually) five petals. The Silverweed (*P. anserina*) has long runners, numerous leaflets (large and small, often in regularly alternating pairs) covered below with silky down, and very large flowers.

263. Hawthorn (*Crataegus oxyacantha*), although generally forming a much-branched hedge-shrub, may reach a

a height of thirty feet or even more, forming a tree (usually with a rounded head) with slender branches which often droop at the ends. The bark on the old parts shows numerous longitudinal furrows dividing it into scales.

The buds are small and have a few spirally arranged scales. They may grow out to form one or other of several types of branches. The bud may develop into (1) an ordinary shoot ("long shoot") on which the leaves are well spaced out and have large, green, toothed, persistent stipules; (2) a "dwarf shoot" on which the leaves are crowded and the stipules are small and soon drop; (3) a dwarf shoot ending in an inflorescence; (4) a "long thorn," towards whose tapering, pointed, hard end the leaves gradually become small, narrow, red scales; (5) a "short thorn," whose tip becomes pointed, hard, and red, and bears two small scales below and several still smaller ones higher up. Both long and short thorns may give off branches in later years. Examine as many plants as possible, noting how the general habit is influenced by the formation of these various types of branches.

The leaves (1 to 2 ins. long) are stalked; the glossy blade is narrow at the base and is divided into three or five lobes, which vary greatly in shape, but are usually more or less toothed. The stipules are roughly $\frac{1}{2}$ -arrow-shaped, toothed, sometimes persistent.

The flowers, arranged in clusters in such a way that they all reach nearly the same level when open, are built on the same general plan as those of the Dog Rose, but the stamens are fewer (about twenty) and there is only one carpel (sometimes two or even three). The sepals are short and narrow; they bend down when the flower opens. The five petals are rounded, white or pink, and attached to the rim of the receptacle-cup by a narrow base. The carpels resemble those of the Rose flower, but the stigmas are broad. The stigma is receptive before the anthers open; at this stage the outer stamens stand erect and the inner ones are bent inwards and downwards so that they do not touch the stigma and self-pollination is prevented.

Honey is produced at the base of the style and is partly concealed by hairs; the flowers are visited by various insects, but their peculiar smell appears to be specially attractive to

flies. The odour is due to a substance (trimethylamine) which is also produced in decaying fish. The flowers can, in the absence of insect visitors, pollinate themselves; as a last resort arrangements for self-pollination are found in many plants. In fine weather *all* the stamens eventually move outwards and the anthers open, but on cold or wet days the inner stamens remain bent inwards and the outer ones shed their pollen over the stigma, causing self-pollination. Why is Hawthorn popularly called "May"? Why is it often called "Whitethorn"? Do you know the "Blackthorn" (Sloe)?

The fleshy part of the fruit ("haw") is formed from the receptacle-cup; the top is thin, so that the hard akene or "nutlet" is here close to the surface. The akene is sometimes called the "stone" because of its hardness, but it differs in nature from the true stone found in the plum or cherry. The "haw" resembles a Rose "hip" in structure, differing chiefly in having a single akene (sometimes two) with a harder wall. Cut the akene open to see the seed inside it. The "haws" are eaten, and the single-seeded akenes dispersed, by birds. When the seed germinates the cotyledons are carried up and become oval green leaves; the earliest foliage-leaves are very like the later ones.

Compare the nature of a thorn, or spine, with that of a prickle. Can a thorn be pushed off, like a prickle? Scrape the rind away from the base of a thorn and from the stem around it; also cut through the stem longitudinally, at the same time bisecting a thorn. Do these experiments show that the thorn contains wood, which is continuous with the wood of the stem? Compare the thorns of Sloe (Blackthorn), Gorse, Buckthorn, and the prickles of Bramble, Raspberry, Borage, Teasel, with those of Hawthorn and Rose.

264. Rowan (*Pyrus aucuparia*) is, like Hawthorn, a small tree (ten to thirty feet high), but in high and exposed situations it may form merely a stunted shrub (see Art. 339).

The Rowan is often called "Mountain Ash," but it is easily distinguished from the true Ash by its leaves, which are alternately arranged and have stipules, those of the Ash being in crossed pairs and without stipules. The leaf has an end leaflet and from two to nine pairs of lateral ones; the pairs of

leaflets are spaced out along the main leaf-stalk. Each leaflet is narrow, oblong, toothed, and from one to two inches long, smooth above, but downy below when young; the old leaflet has scattered hairs on the lower side, especially along the veins.

The bark remains thin and smooth for many years and shows transverse lenticels, but later it becomes thick and furrowed. The resting-buds are long, hairy, blackish, and pressed close to the stem. They may, when they open, grow into ordinary long shoots, or into dwarf shoots which grow very slowly and bear each year only a few closely crowded leaves.

The cream-white flowers are small but crowded in flat-topped inflorescences at the ends of short branches; the inflorescence is circular in outline (4 to 6 inches diameter). The flowers (about $\frac{1}{3}$ inch diameter) open in May or June, and closely resemble those of Hawthorn in structure, their peculiar odour being also due to the presence of trimethylamine and the stigmas maturing in advance of the anthers. They are visited largely by flies and beetles, also by bees; the honey is protected by hairs on the lower parts of the short styles (generally three or four). Note that the axis of the inflorescences branches repeatedly (three or four times), but all the flowers are raised to the same level (of what advantage is this?). Note that the 20 stamens have filaments of 3 lengths (roughly 5, 4, and 3 mm. from the outside inwards).

The fruits are globular (about $\frac{1}{4}$ inch diameter), with scarlet skin and yellow pulp; the hard central part has (usually) three chambers or "stones," each containing a seed. The three ovaries are practically united and the receptacle grows closely around them, so that the fruit has the same structure as the "pome" of Apple or Pear. The berries ripen in August and September, becoming brilliantly coloured and fleshy (until then they are small, green, and hard); they are eaten largely by Thrushes, Redwings, and Fieldfares, as well as by other birds.

† **265. The Rose Family.**—The chief feature which distinguishes this large family (Rosaceae) from the Buttercup family is the presence of what is often wrongly called a "calyx-tube." If you imagine a Buttercup flower in which the receptacle, during the development of the flower-parts, grows up at the sides as a ring which carries on its

edge the sepals, petals, and stamens, leaving the carpels on the central knob, you would have a flower like that of a Cinquefoil, Strawberry, or Blackberry. The cup-like outgrowth involves the sepals more than the other parts, which can easily be detached from the cup. This upgrowth of the receptacle not only tends to enclose and protect the carpels, but also makes the flower tubular and conceals the honey to some extent (there is usually a honey-disc within the bases of the stamens). In Apple, Pear, Hawthorn, Quince, Medlar, etc., the receptacle-cup grows up closely around the carpels, and later on becomes joined to them. Examine also the flowers of Avens, Raspberry, Cherry, Sloe, Agrimony.

Wind-pollination occurs in the Salad Burnet (common on dry, chalky downs), which has small flowers (June to August) in mop-like clusters. Each cluster is made up of a dense mass of both male and female flowers, each of which has a calyx of four sepals. The former have many anthers well exposed to the wind on long filaments, and the latter a tufted stigma mounted on a long style. In this case there is also a provision for preventing the pollination of the female flowers by the anthers of the same cluster; for, not only do the female flowers occupy principally the upper part of each cluster with the male flowers below them, but the latter open later than the former, and distribute their pollen after the females of the same cluster have been pollinated.

Note the following interesting features in the vegetative organs:—the runners of Strawberry and of some Potentillas; the suckers of Raspberry; the long shoots of some Brambles which grow into the soil at the tips, producing roots which contract and pull the tip down, and the formation of new plants in this way; the prickles of Roses, Brambles, Raspberry; the spines of Sloe and Hawthorn; the curious glands on the petiole of Cherry, just below the leaf-blade; the ever-green leaves of the introduced but commonly cultivated Cherry Laurel (thick entire leaves) and Portugal Laurel (thin leathery leaves, slightly toothed), both belonging to the Cherry genus (*Prunus*).

QUESTIONS ON CHAPTER IX.

1. Why are the prickles on erect-growing Roses straight, while those on scrambling Roses are hooked?
2. Describe carefully the structure of a Rose flower. Why is the Dog Rose called a "pollen-flower"?
3. Explain clearly the differences between the prickles of Roses or Brambles and the spines of Hawthorn or Sloe.
4. Describe and compare, giving sketches, the fruits of Rose and Strawberry.
5. Describe the different kinds of leaves on a Strawberry plant. In what respects does a cultivated Strawberry differ from the Wild Strawberry?

6. How does the Wild Strawberry differ from the Barren Strawberry
7. Describe the different forms of branches found on a Hawthorn.
8. Describe the flower of Hawthorn. By what insects is the flower visited, how does it attract insect-visitors, and how is self-pollination hindered?
9. Describe the fruit of Hawthorn, and compare it with the fruits of Rose, Strawberry, and Rowan. To which of these plants is the Hawthorn most closely allied?
10. How could you distinguish in winter, in the absence of leaves, flowers, and fruits, between Rowan ("Mountain Ash") and the real Ash-tree?
11. Compare, by means of a series of sketches with the parts labelled, the fruits of Cherry, Bramble, Strawberry, Potentilla, Avena, Agrimony, Rose, Hawthorn, Rowan, and Apple. Deal only with fruits you have actually examined.
12. Why are Cherry, Sloe (Blackthorn), Plum, Almond, Cherry Laurel, and Portugal Laurel all placed together in the same genus (*Prunus*)? In what respects do they agree? Mention some of their differences.
13. Why are Rowan, Apple, Pear, Service-tree, and White Beam all placed in the same genus (*Pyrus*)? In what respects do they agree? Mention the distinguishing characters of each plant, dealing only with those you have examined.
14. Mention the commonest species of Potentilla, noting the distinctive characters of each, the months when each is most abundant in flower, and the habitat in which each occurs.

CHAPTER X.

VIOLETS, PANSIES, WOOD SORREL, IVY.

266. Violets and **Pansies** are easily recognised by the peculiar structure of their flowers, in which the lowest petal is spurred and the spur contains two nectaries which pass into it from two of the stamens.

The division of the species of *Viola* into "Violets" and "Pansies," adopted here, is a purely artificial one, though convenient when only a few types are studied. The commonest species of *Viola* are (1) *V. odorata* (Sweet Violet); (2) *V. canina* (Dog Violet, so called because commoner than Sweet Violet and scentless); (3) *V. tricolor* (Heart's-ease, with many varieties, including the common Field Pansy, the Yellow Mountain Pansy, and the small Pansies of old-fashioned gardens); and (4) *V. altaica* (the large flat-flowered Pansies of modern gardening). The Violets sold in shops and streets in winter are varieties of *V. odorata*, cultivated in fields in mild climates (Penzance, etc.); it appears to be impossible to grow them successfully in greenhouses. Species (1) and (2) are here called "Violets," species (3) and (4) "Pansies."

In **Violets** the leaves have a long stalk, heart-shaped blade, and small entire or toothed scaly stipules. The flowers are borne singly on a long stalk arising in a leaf-axil; the stalk is curved downwards just below the flower. The young flower is protected by the stipules of the flower in whose axil it arises and also by two small leaves (bracts) on its stalk. When the flower is ready to open, the stalk lengthens and carries up the flower, the bracts being about half-way up and nearly opposite each other. The part of the stalk below the bracts grows erect, but the part above them curves towards the strongest light (facing south when the plant is growing in

an open situation) and at the same time bends over so as to bring the flower into the right position—i.e. with the spurred petal downwards.

In spring (March) get whole plants of Dog Violet (the most abundant British species) and of Sweet Violet (the cultivated forms will do if the wild species is not common in your neighbourhood) and examine them carefully. It is absolutely necessary to watch the plants day by day in order to make out the life-history. The following description of the flower applies in most respects to both of the common wild Violets and to the garden forms of Sweet Violet. Note the following distinguishing characters:—

	DOG VIOLET.	SWEET VIOLET.
STEM.	Usually branched profusely; branches spreading out, but not forming rooted runners.	Parent plant more compact, with rosette of leaves; branches form long rooting runners.
LEAVES.	Usually heart-shaped, but rather narrow and pointed; hairless; do not enlarge after flowers have appeared.	Larger and more rounded and broadly heart-shaped; more or less hairy; grow much larger after flowering is over.
FLOWER.	Scentless; sepals tapering to a sharply pointed tip.	Usually scented; sepals broader, blunt and rounded at end.
CAPSULE.	Hairless or nearly so, usually with three flat sides; flower stalk erect when in fruit; seeds shot out as the three valves contract.	Hairy, more rounded; flower stalk bent downwards, bringing capsule near the soil; seeds merely <i>fall</i> out of capsule.

Apart from a few rare species and varieties, there are two fairly common forms in Britain—(1) Wood Violet (*V. sylvatica*), like Dog Violet but with more tufted (rosette) habit and broader leaves; (2) Hairy Violet (*V. hirta*), like Sweet Violet but with no runners, more hairy, and with the spur longer and hooked at the end.

Note the five free green sepals, each prolonged below its insertion; the five free petals, the upper ones in two pairs (upper pair bent back, side pair spreading out) are lopsided, while the lowest one differs from the others in being

symmetrical and bears a hollow outgrowth (spur) at its base; the five stamens, each with a very short filament; the anthers forming a ring around the ovary and each bearing a triangular orange scale on top. Note the two curious nectaries, which grow from the backs of the two lowest stamens and project into the spur of the lowest petal; the one-chambered ovary containing 20 to 40 ovules on three lines (placentas) on inner surface of ovary-wall (usually three rows of ovules along each placenta); the curious style, with its free end thickened and produced to a sharp beak which projects beyond the cone formed by the anther-scales and hangs over the entrance to the spur of the lowest petal. The style is hollow; at the tip of the beak there is a pore leading into the cavity of the thickened region and thence by a narrow canal at the base of the style into the ovary cavity.

Remove the sepals from a flower and make careful sketches of the inner surfaces of an upper petal, a side petal, and the front (spurred) petal. Turn back the paired petals so as to see into the flower, and make a sketch (enlarged) showing the entrance to the spur and the parts above, below, and at each side of it. Cut the spur open and sketch the two nectaries which project into it. Does the spur simply protect the nectaries (from what?), or does the honey collect in the spur? Remove and sketch one of the three upper stamens (outer face and inner face) and one of the two lower stamens (with nectary). Sketch the pistil (side view); cut across the ovary and sketch the cut surface, showing arrangement of ovules; break off the style, put it in a drop of water on a slide and press it with a cover-glass, noting the air-bubbles which stream from the tip of the beak (what does this prove regarding structure of style?).

The flowers are pollinated by bees whose tongue (proboscis) is long enough to reach the honey (see Art. 267). The anthers open by slits on their inner faces, and the pollen, which is loose and dry (not sticky as in most insect-pollinated flowers), is shed into the cavity above the ovary and around the style. This cavity (which might be called the "pollen-box") is roofed in by the five triangular anther-scales, so that the pollen can only escape (through the space between the tips of the scales and the upper part of the style) when the projecting style-tip (stigma) is moved about. When a bee enters the flower and pokes its tongue into the spur in search of honey, it rubs

against the stigma, shakes the curved style, and thus causes the pollen to fall on to its head, at the same time depositing on the stigma any pollen it has brought from a previously visited flower. If the flower stalk were *erect*, not only would rain get in and spoil the pollen and honey, but the pollen would not fall into the space above the ovary, which is partly closed over by the scales on the anther tops. If the pollen were sticky, the grains would cling to the anthers and could not, of course, be touched by the bee. Some further details of the elaborate pollination-mechanism of Violets and Pansies are given in Art. 267.

So far we have been studying the flowers produced (in Wild Violets) in spring. The flowering-period is short (rarely more than six weeks) and the number of flowers produced is small—especially in Sweet Violets, in which flowering only lasts for a month and a plant produces only about six flowers, each flower lasting about a week in a condition ready for pollination. Except in very bad weather these spring flowers are visited and pollinated by bees, but flowering does not stop when no more of the ordinary flowers are to be seen. The plant goes on producing flower-buds until autumn. Those which succeed the early (normal) flowers do not open but are self-pollinated, so that fruits are continually formed during summer. Finally in autumn a few buds are laid down for the normal insect-pollinated flowers which will open next spring.

In Sweet Violet these closed self-pollinating (*cleistogamic*) flowers have five very small petals and five stamens, but in Dog Violet there are only two stamens (the lowest ones). The anthers produce few pollen-grains (why few?) and do not open; the grains sprout inside the anther, and the pollen-tubes grow through the anther-wall and the stigmatic rim of the gaping style to reach the ovules. The formation of these flowers is partly dependent on shade; they are always shaded by the leaves of the plant itself. If a plant is kept in feeble light, it will usually produce only these cleistogamic flowers.

The fruits of Violets (except *V. odorata*) and Pansies show an interesting mechanism for seed-dispersal. The ripe capsule splits down, midway between the three lines of seeds, into three boat-shaped pieces, and as these dry they contract and squeeze the seeds together; the pressure causes the

polished and slippery seeds to be flicked out forcibly and thrown to a considerable distance (sometimes as much as six feet in Garden Pansies), just as one can flick a slippery orange seed by pressing it between finger and thumb.

It is interesting to compare the general mode of life of these two common species of Violet. The Sweet Violet, growing as it does in hedge-rows or in woods, forms colonies which spread out and thus prevent the loss of light and air which the leaves would suffer if this species grew as isolated plants among the surrounding vegetation. The ordinary flowers, produced in early spring, are few in number; the flower-stalk bends down at the top when the fruit is ripening, and (owing to the feebleness of the ejecting mechanism) the seeds merely fall out or are thrown out only to a very short distance from the parent-plant. A colony, once established, grows in two ways:—

(1) The short thick stem of the parent-plant, bearing crowded bases of old leaves, gives off numerous runners which grow out in all directions, like the runners of Strawberry or Daisy, producing new plants on becoming rooted at some distance from the parent;

(2) The cleistogamic flowers, produced abundantly in late summer and in autumn, give rise to fertile capsules and these are carried downwards, by the bending of the stalk, so as to open close to the soil and scatter the seeds around the parent-plant; sometimes these fruits are thrust into the soil.

By the first method the colony spreads outwards, by the second it becomes denser at the middle, and the net result is the production of large masses of plants which hold their own for year after year by continual replenishment.

The Dog Violet usually grows in more open and less shaded places, and its ordinary flowers appear later than those of the Sweet Violet, when bees are more abundant. These flowers produce abundant seeds, and the erect stalk carries the capsules well above the leaves, so that the seeds are widely scattered. No runners are produced, but colonies are formed by the cleistogamic autumn flowers, which plant the capsules close to the parent, as in Sweet Violet.

Pansies are distinguished from Violets by the large green stipules; the stigma is more elaborate in structure; no cleistogamic flowers are produced.

Examine a Garden Pansy and sketch part of a shoot, noting the green angled stem, the very large lobed stipules; the parts of the flower (Figs. 80, 81). The anthers are locked together by hairs on their edges, so that none of the pollen can escape between them. The dilated stigmatic end of the style is wide open, and has a tuft of hairs on each side; beneath it is a small projection or "scraper." As the bee introduces his proboscis, covered with pollen, he rubs against

the upper edge of this scraper, depositing pollen upon the stigma. Any pollen scraped off as the proboscis is withdrawn will tend to fall away from the stigma.

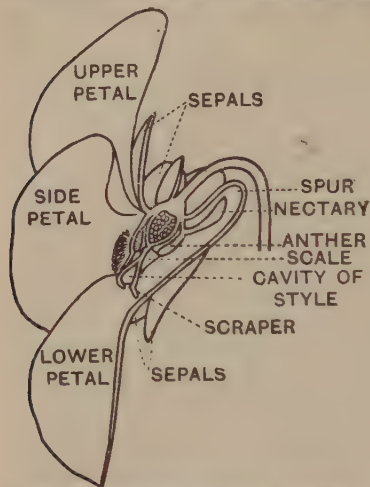


Fig. 80.—Longitudinal Section of Flower of Garden Pansy.



Fig. 81.—Floral Diagram of Violet.

The modern Garden Pansies (*V. altaica*, introduced from Russia about 1810) differ chiefly from the Heart's-ease Pansies (*V. tricolor*) in the larger size of all the parts; the flowers are more nearly circular than oblong (all the petals being spread out to form a disc) and the spur is longer.

Besides the ordinary Wild Pansy (*Viola tricolor*), to which the garden forms sometimes revert when raised from seed, there is a small-flowered variety, the Field Pansy. This is a common annual weed in fields, differing from the typical Wild Pansy in having small white or yellow petals (sometimes none) shorter than the sepals, no scraper on the stigma, and a short spur.

267. Pollination of Violets and Pansies.—The various species of *Viola* afford a beautiful example of a **flower-mechanism** which is practically uniform as regards essential structure and at the same time shows a fairly wide range of adaptations for the visits of different insects (cf. Art. 252, on flower-mechanisms of Papilionaceae). The flowers are *homogamous*, since the style-tip is ready to receive pollen at the time the anthers open (cf. *dichogamy*, Art. 209), but self-pollination is hindered by the projection of the style beyond the "pollen-box." In

Violets the anthers simply touch each other, edge to edge, so that some pollen may escape between them, especially in *V. odorata*, where the two lowest anthers are separated by a vertical opening; most of the pollen, however, can only escape through the small circular slit between the style and the tips of the anther scales. In Pansies the anthers are firmly joined by the hairs on their edges, and the pollen escapes by an opening between the scales of the two lowest anthers, but this opening is separated from the stigmatic opening above it by the stigma-lip ("scraper"). In most *Viola* species plants protected against insects (Art. 195) seldom fruit, but there is nothing which absolutely prevents self-pollination by insects visiting the flower in the proper way. The entrance of undesirable insects—small insects which would not be likely to effect cross-pollination—is hindered by the hairs on the side-petals and (in Pansies) on the sides of the stigma; the opening of the spur is further protected by the overhanging style-beak or the "scraper," the narrow groove on the spur-petal, the hairs lining the entrance and cavity of the spur (which species show one or more of these features most markedly?), and, of course, the length of the spur itself. On the other hand, the visits of long-tongued insects are encouraged by the conspicuous orange-coloured centre of the flower, heightened by the dark streaks ("honey-guides") which stand out vividly from the otherwise light-coloured bases of the spur-petals and side-petals (especially in Pansies) and which (since they follow the veins) converge to the spur-opening.

The flowers are visited chiefly by long-tongued bees. In the common Violets, also in Heart's-ease (*V. tricolor*) and Field Pansy (*V. arvensis*), the visiting insect must have a tongue long enough to reach from the style-beak or "scraper" (against which its head pushes) to the end of the spur. In these species the distance is usually 6 to 8 mm. ($\frac{1}{4}$ to $\frac{1}{2}$ in.), so that the hive-bee (*Apis*) can just get at the honey. The larger humble-bees (*Bombus*) have longer tongues but are not so expert in entering the flowers as is the more slender bee *Anthophora* (proboscis about 20 mm.), which visits so many spring flowers. (See Art. 217 and Art. 276.)

The large flat-faced flowers of Garden Pansy (*V. altaica*) have a longer spur, excluding the hive-bee altogether, and are visited by *Bombus* and *Anthophora*, also by butterflies. The flowers of several alpine *Violas* have still longer spurs, and are pollinated by the longer-tongued butterflies and moths.

268. Wood Sorrel (*Oxalis acetosella*) is a shade-loving plant, growing chiefly in woods and below hedges, also in mountain districts in sheltered rock-crevices.

Note the reddish creeping stem, covered with leaf-bases; the long (three to six inches) leaf-stalk bearing three Clover-like leaflets, often purple on the lower side. Study the movements of the leaflets, which droop at night and on the approach of wet weather, the closed leaf resembling a closed

umbrella. The movements of the Wood Sorrel leaflets are different in some respects from those of Clover. Study these movements carefully and compare with the account already given for Clover (Art. 247).

If you have a microscope you will find, on examining pieces of epidermis torn from the leaf, that the stomates are plentiful on the lower surface, while the upper surface has very few. Does this fact help in the attempt to explain *why* the manner of closing-up of Wood Sorrel leaflets differs from that observed in Clover? When the leaf closes, the three leaflets droop until they become vertical, then each leaflet bends along its midrib (which is pressed to the main leaf-stalk) so that its lower surface comes against the lower surfaces of the other two leaflets. In this way the rate of transpiration is checked, since all the stomates are on the protected lower sides of the leaflets.

Wood Sorrel leaves are much more sensitive than those of Clover to such stimuli as contact (*e.g.* rain, hail, wind) and strong light. Cover a plant so as to darken it, and study the sleep-movements. Keep plants indoors, growing in pots, and note the changes in position of the leaflets on a hot day and on a cool one. Water the plant with a watering-pot, so as to dash water over the leaflets; shake the plant when the leaflets are spread out. Find out where the movements of (1) each leaflet, (2) the main leaf-stalk, take place, and rub these "organs of movement" to see whether this will cause the leaflets, or the whole leaf, to change in position. In what other respects does Wood Sorrel differ from Clover, *e.g.* as to texture of leaflet, length of roots, and how are these differences connected or "correlated" with the differences in the localities in which the two plants grow, *e.g.* as to light, moisture, soil-texture?

The flowers (April to August) are solitary, each arising from the creeping stem on a stalk about as long as the leaf-stalks. What do you notice about half-way up the flower-stalk? Is the stalk quite straight, or does it bend, and where? The flower has five oblong sepals (free, or joined at base?) and five free petals, rounded above and narrow below, white, with purple streaks along the veins. The ten stamens are joined at the base; note the different lengths of the filaments, five of the stamens having filaments which nearly

equal the styles in length, while the five alternate stamens have much shorter filaments. Sketch the stamens, then remove them and note the ovary, which is five-lobed and five-chambered, and the five long styles.

The flowers of Wood Sorrel are fairly conspicuous on account of their large spreading white petals; the coloured streaks on these make the flower more attractive and also serve as honey-guides. The conspicuousness of the flowers is enhanced by the bright green colour of the leaves, especially when so few other plants are in leaf, as is the case in early spring in the places where Wood Sorrel grows. Hence the flowers are easily seen by the few insects that are about in early spring, and since they are shallow and the honey is readily accessible, they have a much better chance of cross-pollination than the more highly specialised flowers of Sweet Violet, which appear at the same time of year. Even flies and beetles can reach the honey in the shallow Sorrel flower, which is therefore not dependent on the larger and longer-tongued insects, as is the case with Violets.

Like the Violet, however, Wood Sorrel relies largely upon small and inconspicuous cleistogamic flowers for its propagation. In these flowers, produced in late summer or in autumn, the number of pollen-grains developed in the anthers is remarkably small (about a dozen in the smaller anthers, two dozen in the larger ones), but the capsules produced are much larger than those arising from the ordinary open flowers.

The fruits produced by the cleistogamic flowers are thrust downwards into the soil, or at any rate brought close to it, by the downward curvature of the flower-stalk. The fruits produced by the ordinary flowers, however, show a remarkable mechanism for the scattering of the seeds. Examine fruits of different ages, cutting them across to see the chambers (how many chambers, and how many seeds in each?). In ripe fruits notice that some of the chambers may be empty; if so, find the slit through which the seeds have escaped. This suggests that the seeds are in some way forced out of the chambers, the longitudinal slit running down the middle of the chamber-wall closing up again at once.

How do the seeds escape? Try squeezing ripe fruits between the fingers until you succeed in causing seeds to

spring out. How far may a seed be jerked away? By carefully examining (1) a ripe fruit with the seeds still inside, (2) a fruit from which the seeds have escaped, (3) the seed itself both before and after its escape, you should be able to discover that the seed has a thick fleshy extra coat (*aril*) covering it like a cup, and that this coat, by suddenly turning inside out, causes the seed to be shot out of the fruit through the slit in the chamber-wall.

In plants which you have dug up and set in pots indoors, study the movements of the flower-stalk as well as those of the leaf. Note that the stalk at first droops, before the flower-bud has opened; then it becomes erect, so as to expose the flower to the sky and attract insects; after pollination the stalk bends downwards again; finally, when the fruit is ripe, the stalk becomes erect and also grows in length.

Are these the only movements of which the flower-stalk is capable? What do you notice on dull and wet days as compared with bright weather? Does the stalk droop at night? Does the flower close at night?

269. Ivy (*Hedera helix*).—As is well known, this plant climbs up walls, tree-trunks, and other supports by means of numerous roots which spring from the stem along the shaded side, or creeps along the soil, especially on banks and under hedge-rows. It is not a parasitic plant; when growing on a tree-trunk, the roots simply fix the plant to the bark and do not penetrate the trunk or tap the tree's supplies of water and food. Occasionally one sees an old Ivy plant whose main soil-root has died away, but in most cases the Ivy draws its water from the soil by its main root, the climbing roots serving for fixation.

Examine Ivy plants growing in different positions, *e.g.* on level soil, on sloping banks, on trees, on walls. Note the arrangement and form of the leaves. The leaf-blades differ considerably in shape, but there is always a central vein, running to the middle lobe, and two pairs of side veins which run into the side lobes when these are present. On flowering-shoots the leaves are arranged spirally, so as to form five rows, and the blades are not lobed; these shoots are only formed when the plant is well exposed to light (why?) and

they project from the rest of the plant, having no climbing roots.

On the ordinary branches the leaves are arranged in two rows along the flanks of the stem. Note (1) the leaf-base, partially ensheathing the stem; (2) the cylindrical stalk; (3) the blade, dark green (often pale along the veins or in patches), glossy, leathery. Of what advantage is the possession of thick leathery leaves to an evergreen plant? Do you know of any other evergreen plants with broad leaves protected in this way? Which part of the leaf (base, stalk, or blade) brings the blade into the best position for light? Careful inspection shows that the young leaves are all alike, but by the bending of the leaf-base, the amount of lengthening of the stalk, and the amount of growth in size of the blade, the blades all come into nearly the same plane and "fit together," so that they get as much light as possible and do not shade each other. The blades form what is termed a "leaf-mosaic" (see Art. 153).

Examine a shoot in autumn or winter, and dissect the conical pointed buds; note the axillary buds, each more or less sunk in the base of the leaf-stalk. The bud is covered with down, consisting of minute star-shaped scale-hairs, which can be seen scattered over the stem and leaves after the shoot has grown out; by noting the arrangement of these hairs it is easy to trace the amount of growth of stem, leaf-stalks, and leaf-blades.

The flowers, which open about October and have a rather unpleasant odour, are borne on special branches, whose leaves have already been described. They are arranged in globular clusters at the ends of these shoots; there is usually a cluster at the end of the shoot, and below this either a few similar clusters or a few single flowers. In each cluster the flower-stalks all come off at one point; an inflorescence of this kind, with the youngest flowers in the centre, is called an *umbel*, and may be likened to a raceme in which the main axis stops growing in length after giving off the first flower.* Note the very small calyx with five slight lobes on its edge; the five green petals, which serve to protect the inner parts and soon

* Frequently there are a few isolated flowers below the umbel; these were given off before the axis stopped elongating so as to produce the umbel.

fall off; the five stamens, which alternate with the petals and which shed their pollen before the stigma of the same flower becomes receptive; the short stigma, surrounded by the yellow-green honey-disc which lies on top of the ovary. Cut across the ovary: how many chambers does it contain, and how many ovules in each chamber? The honey is freely exposed, and the flowers are visited largely by short-tongued insects (flies and beetles), as well as by bees and wasps.

Examine the black ripe fruits ("berries"): do all five chambers produce seeds? The hard covering around the seeds is formed from the ovary-wall, so that the Ivy "berry" is really a kind of "stone-fruit" or *drupe*. The fruits are eaten and dispersed by birds.

QUESTIONS ON CHAPTER X.

1. Which of the two common Violets seems to rely most on its cleistogamic autumn flowers for its propagation?
2. Why are the scentless flowers of Dog Violet carried on longer stalks than the scented flowers of Sweet Violet?
3. Describe, from your own observations, the method by which the capsule of a Violet or a Pansy throws out the seeds. Give sketches from what you have actually seen.
4. In what situations do the two common species of Violet grow? State, and as far as possible explain, how each is adapted to its mode of life.
5. Draw up a tabulated comparison between Violets and Pansies. Try to account for the more striking differences.
6. Compare a cleistogamic Violet flower with an ordinary flower, and explain the differences.
7. Explain, with sketches, the structure and the mode of pollination of a Violet and of a Pansy.
8. Describe carefully, with sketches from your own observations, the sleep movements of a Wood Sorrel leaf.
9. Compare the leaves of Wood Sorrel with those of Clover, and try to account for the differences noted.
10. Describe the movements of the leaf of Wood Sorrel. Compare with those of Clover leaf. From your own experiments, state the conditions under which the movements occur.

11. Describe, from your own observations, the movements executed by the flowers of Wood Sorrel. Which of these movements are "spontaneous," and which are "induced" by changes in the surroundings?

12. Describe carefully the structure of a Wood Sorrel flower (ordinary kind) and point out its adaptations for pollination. Give sketches.

13. Describe the structure of the fruit of Wood Sorrel and the mechanism by which the seeds are discharged, giving sketches from actual fruits you have examined and experimented with.

14. Why are the ordinary capsules of Wood Sorrel raised well above the rest of the plant? How do the capsules produced by the cleistogamic flowers differ from those produced by the ordinary (spring) flowers, and why?

15. Describe the appearance of a twig of Ivy, with a sketch, and explain the features shown.

16. Describe a simple experiment designed to show that the climbing-roots of Ivy are insensitive to gravity but sensitive to light.

17. Describe the structure of an Ivy flower, and compare it, as regards its pollination, with the flowers of Wood Sorrel and a Violet or Pansy.

CHAPTER XI.

LING (HEATHER), HEATH, BILBERRY, CROWBERRY.

270. Ling, Bell Heath, Cross-leaved Heath.—These closely allied plants usually occur together on heaths and moors, playing an important part in the formation of peat. They are all much-branched wiry shrubs, bearing crowded small narrow leaves. Each leaf is rolled up so that the lower epidermis (bearing the stomates) forms the inside of a tube which is open to the air only by a narrow slit (seen as a white line along the lower side of the leaf); the edges of the leaf bear hairs, which still further hinder the escape of water-vapour from the leaf.

In the **Ling** or **Common Heather** (*Calluna vulgaris*) the leaves are very short and arranged in crossed pairs, forming four rows on the numerous branches. The copious branching, the minute size of the leaves (2 or 3 mm. long, about 0·5 mm. broad), and the closely arranged four rows of leaves on each branch at once distinguish this plant from the Bell Heath. The leaves overlap each other, and each is grooved below and produced on each side at the base, so as to be somewhat spearhead-shaped.

The rosy drooping flowers are small and arranged in dense spikes at the ends of branches. Both calyx and corolla are rosy and four-lobed; the corolla is shorter than the calyx. Below the calyx there are four bracts in two pairs, the lower pair leaf-like, the upper pair membranous. Carefully examine the eight stamens; note the peculiar horn-like appendages on the outer side of each anther, and the

two pores by which the anther opens at the apex. A bee entering the drooping flower rubs against the stigma and then, in pushing up its proboscis for the honey (produced by a ring-like nectary around the base of the ovary),* comes



Fig. 82.—Sprig of Cross-leaved Heather (*Erica Tetralix*).



Fig. 83.—Vertical Section of Flower of *Erica*.

against the anther-appendages and shakes the anthers, bringing a shower of pollen down on its head. The ovary is four-chambered, with numerous ovules in each chamber. The fruit (capsule) is enclosed by the corolla, which fades to a brown colour after pollination has occurred. It ripens in autumn, and next spring opens by four slits; the seeds are very light and are dispersed by the wind.

In **Bell Heath** or "**Scotch Heather**" (*Erica cinerea*) the leaves are longer than those of Ling, about 6 mm. ($\frac{1}{4}$ inch) long and 1 mm. broad; they are arranged in threes (sometimes in fours) and are not so crowded on the stem.

The flowers are red-purple, larger and less densely arranged than those of Ling. The sepals are green, long, narrow; the corolla is more bell-like; the ovary hairy.

The **Cross-leaved Heath** (*Erica tetralix*) differs from Bell Heath in several respects. The stems rarely exceed a foot in

* As is well known, Ling is an important source of honey; "heather"-honey has a reddish colour and a peculiar flavour. The flowers are, however, largely *wind*-pollinated; the pollen is dry and light, escaping in clouds when the plant is shaken violently.

height; the leaves (in fours, or sometimes fives) are bluish below, with a wide slit, and are much less rolled up. The lower side of the leaf is downy, and the margins bear gland-hairs.

The flowers (Figs. 82, 83) are in clusters at the ends of the branches; each cluster consists of a few flowers, all turned in the same direction. They are pinkish, and larger than in Bell Heath; the ovary is covered with hairs.

This plant is not nearly so gregarious as Ling and Bell Heath; it is chiefly found in the moister places on heaths and moors, the individual plants being scattered or forming small groups instead of covering large areas.

It is interesting to compare the mechanism of the flowers in these three plants. In the two Heaths the flower hangs down and the narrow mouth of the corolla is nearly closed by the stigma. The pores are at the sides of the anther-tips; and since the anthers are pressed against each other in a close ring, the pollen cannot easily fall out, unless the anthers are loosened and shaken about—as happens when a bee pushes against the appendages of the anthers. These appendages—twenty in all to each flower—nearly fill the space between the anther-ring and the inside of the corolla, so that the bee must displace them in entering the flower; the appendages act as levers, causing the anthers to separate. Self-pollination is prevented by the position of the anther-pores, and the bee first deposits on the projecting stigma any pollen it has received from another flower. In Heather (Ling) the flowers are nearly horizontal and the stamens and style project upwards, so that here the bee pushes its head and tongue below these parts, and the pollen is less likely to be wasted than in a drooping flower. The shallow flowers of Ling are visited by flies as well as by all sorts of bees, but in the Heaths the distance from the anther-appendages to the bottom of the corolla is too long (about 8 mm.) for the hive-bees. The Heaths are pollinated by humble-bees and butterflies, but the hive-bee regularly bites through the corolla; one often sees nearly every flower over a large area with holes drilled by hive-bees.

271. Bilberry (*Vaccinium myrtillus*) is so commonly associated with Ling and the Ericas on heaths and moors that it should be studied along with them, especially as it belongs to the same family.

(Ericaceae). It differs from these plants in several important points. Its leaves are broad and thin, with toothed edges, and are not evergreen; the corolla is nearly globular with a narrow mouth, and the stamens have appendages, but the calyx is merely a narrow rim, the ovary is *inferior*—i.e. below the rest of the flower, and the fruit is a *berry*. Examine the plants, noting the green ridged branches; in the drooping flower (Fig. 84) note that the anther-pores are pressed against the style, so that pollen cannot fall out unless a bee pushes against the appendages and shakes the anthers.



Fig. 84.—Flower and Stamen of Bilberry.

272. The Crowberry (*Empetrum nigrum*) is an evergreen “ericoid” (heather-like) plant with narrow rolled-up leaves, though not at all closely related to the Heather family. It grows, often along with Ling, Ericas, and Bilberry, on heaths and moors. It is rare in the south of England, but in the north, e.g. on Yorkshire moors, it is often the dominant plant over large areas.

The leaves, about the same size as those of Cross-leaved Heath, are mostly in whorls of three or four. Each is rolled up even more completely than in Bell Heath and contains a relatively wide air-cavity, with a narrow slit along the lower surface; the margins of the slit are covered with hairs, those on the two sides interlocking and thus making the leaf an almost closed tube.

The flowers are very small and completely unisexual, the male and female flowers being on separate plants; they are carried in the axils of the upper leaves. Each flower is stalkless and has three sepals and three petals, all of them pink or purple, with a few bracts below these. The male flower has three stamens, whose anthers are pushed well out of the flower on long filaments. The female flower has an ovary with about six chambers, a short style, and about six spreading stigmas. The flowers are, chiefly at any rate, pollinated by the wind. The fruit is black, globular, fleshy, with a single stone; it is a drupe, not a real berry.

† **273. Moorland and Bog Plants.**—Moorland plants are exposed to high winds, which not only increase transpiration, but prevent the growth of trees. This is not so marked on low moors (heaths,

commons), where such trees as Pines and Birches flourish, with Alders, Willows, and Bog Myrtle beside streams and in wet places. On high moors the entire vegetation is stunted and dwarfed, and most of the plants have narrow leaves or other adaptations for preventing excessive transpiration. The rainfall is high—over 100 inches a year, for instance, on the higher parts of Dartmoor, the moorland area with which I am best acquainted. The frequent mists help to keep the moor very moist, and the summit of Dartmoor forms a boggy plateau or basin, riven in all directions by crevasses which form an intricate network and gradually give rise to streams: the chief rivers of Devon arise from this desolate Cranmere region. The chief plants found in the boggy and crevassed parts are Sedges, Rushes, Cotton Sedge* (easily recognised in summer by its tufted white fruits), Bell Heath, great cushions of Hair-moss (*Polytrichum*) and Woolly Fringe-moss (*Rhacomitrium*), and Bog-mosses (*Sphagnum*) in the wetter places; tufted and narrow-leaved Grasses (Ch. XVI.) on the hill-sides; Bilberry on the dry and wind-swept ridges; Rushes, Bog-mosses, dwarf Birches, Rowans, etc., along the streams.

The Rushes, Sedges, and Grasses found on moors mostly belong to different species from those found in ordinary marshes on low-lying areas. On low moors we find chiefly Ling, Heaths, Gorse, Bracken, and low (often creeping) plants which shelter under these—e.g. Tormential, Heath Bedstraw, Milkwort (*Polygala*), Lousewort (Red Rattle)—and in the boggy places various bog and marsh plants. The leaves of Ling, Heaths (*Erica*), and Crowberry are protected against excessive loss of water by being rolled up. The Bilberry has broad, thin leaves, but these fall off early, and the ridged green branches carry on photosynthesis without exposing much surface for transpiration. Sedges and Rushes have narrow leaves with thick cuticle, while moorland Grasses either bear on their upper surface triangular ridges, and can roll up longitudinally in dry weather so as to expose a very small surface for transpiration (the green tissue, with stomates, lines the furrows between the ridges), or are narrow and permanently rolled up. The leaves of Bracken plants growing on heaths have thicker cuticle, less spongy tissue, and fewer stomates than those of Bracken growing in moister and more sheltered places; the same applies to other species which grow both on heaths and in less exposed places.

One naturally associates Ling and the *Ericas* with hills, but extensive heaths are found at various parts along the coasts of Britain, only a few feet above sea-level. Ling and the *Ericas* occur at all elevations up to about 2,000 feet; above that height they are often replaced by Bilberry. In the south of England, at any rate, the Bilberry often occurs in dry woods; altitude in itself has but little direct influence on the distribution of this and of other heath plants, and one finds every transition from typical heather-moors or heaths to forests and woodlands. Heath-areas may be very dry or very moist, often passing into marshy land. Dry heaths overlie sand or chalk, from which water drains quickly; the average summer temperature is

* Also called "Cotton-grass," though it is not a Grass.

low; the soil thin and poor in plant-food, often only a few inches thick and forming the only reservoir from which the plants draw their water in summer.

In the Vegetation Maps of Yorkshire* and in other records of botanical surveys, several types of moorland are distinguished, each being named after the dominant (most abundant or most characteristic) plant—*e.g.* Cotton-Sedge moor, Heather moor, Rough Grass moor.

The typical bog occurs on heaths and moors, associated with the heath plants already mentioned, and its vegetation consists of peat-forming and peat-loving plants. The distinctions between a marsh (Art. 258) and a bog are fairly clear in most cases, though there are transitions from one to the other. The typical marsh occurs on low ground, its water is rich in mineral substances, especially lime, and its plants grow rapidly, either becoming tall or remaining low, but producing numerous leaves and branches each year. In the typical bog the water is poor in lime and other salts, and the plants are mostly slow-growing and of low stature. Peat-bogs, like the heaths or moors on which they occur, are found at all heights, from a few feet above sea-level up to three thousand feet. The peaty soil in which bog plants grow is not sufficiently aerated for the proper formation of nitrates, so that although such soils (bog, peat, morass) often appear on analysis as though they should be extremely fertile, very little of the materials they contain is directly available to serve as plant-food.

As in the case of many marsh plants, most bog plants have more or less well developed xerophilous characters, due largely to the excess of peaty acids, which makes water-absorption difficult. Mosses, especially the Bog-mosses (*Sphagnum*), of which many species and varieties have been distinguished, play an important part in the formation of bogs. The Bog-mosses, whose appearance and remarkably spongy character are well known to all who have walked over our moors, are specially adapted for storing water. The leaf of a Bog-moss consists of a single layer of cells, which are of two kinds: (1) large empty cells with pores on the walls, (2) small green cells. The green cells are long and narrow, forming a network, each mesh of which is occupied by one of the empty cells; the green cells carry on the living functions, while the large clear cells store up water. Each plant branches and grows upwards, while the lower parts die and lose their green colour, but are preserved from decay by the absence of oxygen and the presence of the peaty acids. In this way great masses of peat are formed.

The flowering plants found in bogs include, among many others, Bog Asphodel, Bog Orchids, Bog Myrtle, Grass of Parnassus, Bog Cinquefoil (*Comarum palustre*), Marsh Gentian (*Gentiana pneumonanthe*), Bog- or Buck-bean (*Menyanthes*), Bog Pimpernel, Sundews (*Drosera*), Butterwort, Bladderwort. The last three plants catch and digest insects. Most heath plants (Ling, Heaths, moor Grasses) have a covering of Fungus-threads on or in their roots, forming a symbiosis (Art. 253) and

* *Botanical Map of Leeds and Halifax District*, by Smith and Moss (Bartholomew and Co., 1s. 6d.).

enabling them to absorb decaying vegetable matter (humus) ; a similar "fungus-servant" or *mycorhiza* occurs in most forest trees.

For a more detailed account of the adaptations of heath, bog, and marsh plants see *Plant Biology*, Ch. IX. ; also the portions of that work which deal with humus, saprophytes, insectivorous plants, etc.

QUESTIONS ON CHAPTER XI.

1. How could you distinguish between Ling, Bell Heath, Cross-leaved Heath, and Crowberry, merely from leaf-bearing branches without flowers ?

2. Describe the structure of the leaf in each of these four plants, and explain how the structure is adapted to the habitat.

3. Describe the flowers of Ling, Bell Heath, and Cross-leaved Heath, pointing out their differences and explaining the pollination mechanism.

4. Describe the flowers and fruits of Crowberry. Compare this plant with the Ericaceous moorland plants.

5. How can you explain the fact that most moorland plants, e.g. Ling, Heaths, Crowberry, are protected against free transpiration, although moors get so much moisture in the form of rain and mist ?

6. Why is the vegetation of a high moor dwarfed, with no trees, while low moors (heaths) are often dotted with tall trees ?

7. In what respects do many moorland plants agree with plants growing on sandy coasts and in salt marshes ? How may these resemblances be explained ?

8. What is the difference between a marsh and a bog ?

9. Write an account of the vegetation you might expect to find growing on a swampy moor, and indicate any points in which the plants appear to be structurally adapted to such an environment.

10. Write a list of plants which you have found on moorland walks. What peculiarities of leaf-structure have you observed in any six of these ? How does the possession of such peculiarities profit the plant ? What was the nature of the soil on which the moorland plants grew ?

CHAPTER XII.

PRIMROSE AND COWSLIP.

274. Primrose and **Cowslip** flower chiefly in April and May, and their flowers are similar in structure.

In the **Primrose** note the thick stem which grows in the soil bears crowded bases of former leaves, together with numerous roots, and stores up reserve food; the pale green

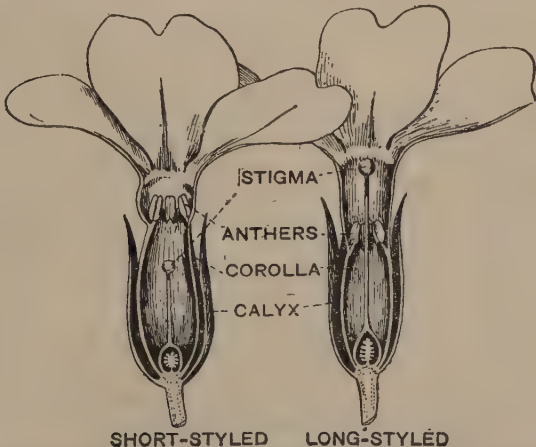


Fig. 85.—Vertical Sections of Short-styled and Long-styled Flowers of Primrose

leaves, arranged in a rosette at the growing end of the stem, each being about three inches long, with a broad midrib veins very prominent on the lower side of the toothed and wrinkled blade.

The flowers (Figs. 85, 86), each carried on a hairy pinkish stalk, appear to arise singly from the stem, but close inspection shows that they really form an umbel, since all the stalks are joined at the base to a short outgrowth from the stem. Note the bract on the flower-stalk; the inflated and five-angled calyx with five narrow pointed lobes; the corolla, consisting of a *tube* and a flat broad upper portion, the *limb* with five notched lobes. The corolla-lobes are pale yellow, but round the mouth of the tube there is an orange-coloured ring with thickened folds; this ring is sometimes represented by five patches (one to each lobe) darker in colour than the rest of the expanded limb. The limb serves as a platform on which the insect-visitors (chiefly bees) stand, and the orange ring acts as a honey-guide, enabling the insect to reach the centre of the flower more quickly and certainly.

Note the five stamens, which are, in some flowers, at the mouth of the tube, and can then be seen to stand opposite to the lobes; it is characteristic of the Primrose family (Primulaceae) to have the stamens equal in number to the corolla-lobes and opposite to (not alternate with) the lobes. Open up the corolla-tube of a flower of this kind ("thrum-eyed"): the filaments of the stamens are very short and are inserted near the mouth of the tube, while the stigma is about half-way up the tube. Note the structure of the ovary: it is one-chambered, and the numerous ovules are attached to a rod (placenta), which projects from the floor of the chamber upwards but does not reach



Fig. 86. Floral Diagram of Primrose.

the roof, so that the ovary-wall may be removed leaving the ovules attached to the free central placenta.

Now examine other flowers on (1) the same plant which bears the kind of flower just described, (2) other plants. Do you find that (1) *all* the flowers on the first plant are "thrum-eyed" (short-styled), (2) some plants have a different type of flower in which the *stigma* is at the mouth of the tube, while the stamens are inserted half-way up?—this is the

“pin-eyed” or long-styled form. The two kinds of flower appear to be always on distinct plants, and the plant apparently produces flowers of the same kind year after year. So that there are evidently two varieties of Primrose, differing only in the relative lengths of stamens and style; in the two types the positions of anthers and stigma are simply reversed. In which case does self-pollination seem to be possible or likely to occur, and in which does it appear to be hindered?

Cover flowers of each kind with muslin, and find out whether self-pollination does occur in either kind. With the microscope examine the pollen-grains and the stigma of each kind of flower, noting that the higher anthers (i.e. those of short-styled flower) produce larger pollen-grains (about $\frac{1}{700}$ inch diameter) than those of the long-styled flower (about $\frac{1}{1000}$ inch diameter); the long style is globular and rough with small projecting hairs, while the short style is rather flat-topped and smooth (with very short projections). Possibly the difference in size of the pollen-grains may be due to the fact that the larger grains have to send a longer pollen-tube down the long style to reach the ovary. Perhaps also the longer stigmatic hairs are required to catch and hold the larger grains, which would tend to roll off the nearly smooth stigma of the short-styled flower.

The fruit (capsule) of Primrose opens by five teeth at the top, each tooth being notched in the middle. This, together with the minute structure of the ovary-wall and the occasional production of “monstrous” flowers in which the pistil is represented by five leaves, affords evidence that the Primrose pistil is made up of five carpels. It is not always easy to tell at once how many carpels go to form a pistil which apparently consists of a single piece, as in this case.

275. In the **Cowslip** the leaf-stalk is “winged” below the blade, not forming a bare midrib at the base of the blade as in Primrose. The flowers are carried up on a general stalk or inflorescence-axis and are arranged in an umbel, each flower having a stalk of its own. The corolla is smaller than in Primrose; the tube is shorter and its “throat” is dilated below the mouth, which is more funnel-shaped than in Primrose. The orange-coloured honey-guides are very conspicuous, forming a patch opposite each of the five lobes. The flowers are heterostyled, as in the Primrose.

†276. **Note on Pollination of Primrose and Cowslip.**—In both of these plants honey is produced at the bottom of the corolla-tube, and the flowers are visited largely, in fine weather, by bees, butterflies, and moths, whose tongues are long enough to reach the honey. It has been found by experiment that, on the whole, "legitimate" cross-pollination (transference of pollen from long-styled flower to stigma of short-styled flower, and *vice versa*) yields better results (more seeds germinate and stronger seedlings are produced) than "illegitimate" cross-pollination, while both kinds of cross-pollination are better than self-pollination. However, the manner in which the pollination of the Primrose actually occurs in nature has been for many years the subject of conflicting statements by various observers.

The following extracts from a paper by Professor Weiss (*New Phytologist*, 1903), based on observations made in Shropshire during the Easter vacation of 1903, are given not merely because they are of interest, but in the hope that they may induce observers in various parts of the country to take up the subject.

The chief insects seen visiting the flowers were species of short-tongued burrowing-bees (*Andrena*), hive-bees (*Apis*), small humble-bees (*Anthophora*), large humble-bees (*Bombus*), and a fly called *Bombylius* (see Art. 211). "Considering the regularity of the visits of *Bombylius* and the relatively large number observed in really fine weather, I have no doubt that this insect is an active agent in the pollination of the Primrose. It seems admirably adapted to obtain nectar from the depths of the tubular corolla with its long proboscis, and it seemed at this time of year to confine its attention to the Primrose. Only on one occasion did I observe a *Bombylius* sucking nectar from the Celandine, which is so largely visited by the bees. . . .

"On five different occasions I have observed *Bombus* visiting Primroses, and generally in such a manner as to ensure the pollination of the flowers. In two cases, however, I noticed the humble-bee not sucking at the flower, but moving all over the corolla, apparently endeavouring to obtain the honey by illegitimate means, just as Darwin observed them at times biting through the corolla in the case of the Cowslip, of which they are regular visitors. I ought to state clearly that *Bombus* was a more frequent visitor of other flowers than the Primrose, and was more commonly seen on the Willow, the Dandelion, the Violet, and the Barren Strawberry. A smaller humble-bee, however, *Anthophora*, though less plentiful in the district, was more often seen on the Primrose, to which it seemed to confine its attention. There can be no doubt that this insect is both able to gather honey from the Primrose flower and also to effect its pollination.

"The honey-bee, *Apis mellifica*, appeared to be less hardy than the humble-bee or *Bombylius*, for it only gathered honey on warm days and was not observed at all on several days when *Bombylius*, *Bombus* and *Anthophora* were about. The bees visited chiefly the Celandine, Barren Strawberry, Wood Anemone, Violet, and Dandelion. Occasionally a stray one would visit a number of Primroses, but did not spend much time on each. They were evidently endeavouring to obtain the

nectar, which however they were unable to reach. They stayed a little longer on the short-styled flowers, from which they collected a little pollen. They were obviously not the regular visitors of the flowers, although they could no doubt bring about cross-fertilisation of the long-styled forms. This would also be effected by the visits of *Andrena gwynana*, but this insect must be placed in a different category from the bee, for it is a regular and busy visitor of the Primrose and more often seen by me on its flowers than on those of other plants. It was only observed towards the close of my visit when the weather was much milder, but then it was present in considerable numbers. It gathered the pollen greedily and in getting at it poked its head deep into the mouth of the corolla.

"From the instances given above, therefore, there is no doubt in my mind that Primroses are efficiently cross-pollinated in the district under observation by *Bombylius*, *Anthophora* and *Andrena*, with the addition of occasional though by no means isolated visits of *Bombus*.

"That self-pollination may occur fairly often in the Primrose cannot be denied, and, indeed, Darwin observed the frequent occurrence in both Cowslip and Primrose of Thrips, which he considered aided the self-fertilisation of both forms. In many Primroses which I examined numbers of Thrips were present, and in these flowers it was very common to find pollen-grains scattered throughout the tube of the corolla and it seemed likely that it had been carried about there by these small insects. Another agency for self-pollination is no doubt the wind, taken in conjunction with alterations in the position of the flower.

"In the absence of cross-pollination, which must frequently fail in flowering plants in early spring, the strong winds of that season are probably of considerable use. In the Primrose the flowers open at first in a vertical position, and if the flower is short-styled the pollen from the opening anthers can readily be shaken by the wind on to the lower-standing stigma. But towards the end of flowering the flower-stalk has grown considerably in length and the flower passes into a horizontal and often a pendant position, so that the long-styled forms have a chance of self-pollination too when the flowers are agitated by the wind.

"It may be thought that this movement is mainly for the concealment of the fruits which in the Primrose are ripened beneath the foliage, but though this may be to a certain extent the case, I cannot but believe that the self-pollination is also a determining factor in this movement. For in the Cowslip the very opposite occurs. The flowers, at first pendant, offer greater facilities as far as self-pollination is concerned to the long-styled forms, but later on the flowers become erect and thus in the absence of cross-pollination the short-styled forms will have ample opportunity to be self-pollinated.

"From the observations I have made on the Primrose I feel convinced that it is both regularly visited and cross-pollinated by insects under favourable climatic conditions, but that like most flowers adapted to the visits of insects it is provided with efficient means for self-pollination, and these are important to a plant flowering at so early a period of the year, when the visits of insects may be precarious."

Watch insects visiting the flowers of Primrose and Cowslip : in the former case the flat top of the erect corolla serves as a platform, in the latter the insect enters the drooping flower from below. Why is the top of the corolla narrow and cup-like in Cowslip, instead of being broad and flat as in Primrose ? Why do Primroses usually grow in woods or on slopes and banks, while Cowslips grow mostly in open and level meadows, often among long grasses ? Does the possession of a long flowering-axis in Cowslip, carrying up the flowers in a tuft, as compared with the arrangement in Primrose, seem to be connected with the different situations in which the two plants grow ?

QUESTIONS ON CHAPTER XII.

1. Draw up a comparison between Primrose and Cowslip as to habitat, leaf, inflorescence, and flower.
2. Describe the structure of a Primrose flower, pointing out the differences between the two types of flower.
3. Describe and discuss the pollination of the Primrose. Do you consider heterostyly plays an important part in promoting cross-pollination ? Give reasons for your answer.
4. Describe the pollination of the Cowslip, and point out how it differs from the Primrose.
5. Describe the fruit of Primrose and Cowslip.

CHAPTER XIII.

POTATO, BITTERSWEET, GOOSEGRASS.

277. Potato (*Solanum tuberosum*).—Examine tubers and also whole plants (freshly dug up); plant tubers in soil and in sawdust, keeping some in darkness and others in the light.

Since the tubers themselves can be at once obtained at any time of year, we will take them first. Do any of the tubers show at one end a stalk or the withered portion of a stalk? Notice the “eyes”; each eye is a small outgrowth sunk in a pit on the surface of the tuber. Carefully examine one of the larger eyes: is it a solid body, or does it bear any appendages? What do you think the eye *is*? Are the eyes scattered all over the tuber uniformly, or are they more numerous at one end of the tuber? Can you make out that the eyes are crowded at the end furthest from the remains of the stalk which attached the tuber to the parent plant? If so, we may call one end the “eye end” or “bud end” or “growing end,” the other the “stalk end” or “barren end.” Have the eyes any definite arrangement on the tuber, or are they scattered anyhow over its surface?

Try to determine the position of the eyes on a Potato tuber by fixing a pin in each eye and joining the pins by a piece of thread. The eyes are arranged in a spiral, the sixth eye being in a straight line with the first; the thread in going from the first to the sixth eye goes around the tuber twice. Compare this arrangement with that of the buds on an Oak twig and of the leaves on a Wallflower (see Art. 152).

Plant tubers in the garden or in pots, some in moist sawdust, some in moist soil; some in water, some in damp air in covered vessels; some with the bud end upwards, some with

this end downwards; some cut in two, separating bud end from stalk end, some cut into several pieces with an eye or without an eye. After a week or two, when the buds begin to sprout, it will be easy to tell the bud end from the stalk end. Will the buds sprout if a tuber is kept in darkness? Do all the specimens gain in weight? Which do not? In the case of specimens that gain in weight, where does the extra material come from? In the case of specimens grown in darkness, at what stage do they die? In what other respects do specimens grown in darkness differ from those grown in the light? Why do tubers with sprouting buds turn soft? Chop up some sprouted tubers, shake up the pieces in water; then filter, and test the filtrate for (1) starch, (2) sugar.

In examining plants grown from tubers, note that the new tubers are simply the swollen ends of branches, which

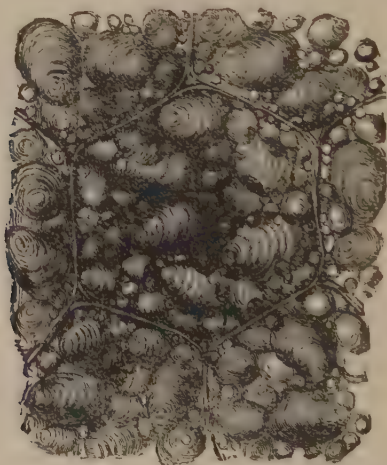


FIG. 87.—Cells of Potato, showing Starch Grains, greatly magnified.

can be traced back to the lower part of the stem and arise from it in the axils of small leaves. In seedlings it is easy to make out that the tuber-bearing branches come off above

the cotyledons, so that the tubers are not roots, being developed above the root-system. Why are potato-fields ridged, with the plants occupying the ridges? Why is the soil heaped up around the plants? What happens if you do not "ridge" a Potato-plant in the garden? Have you ever seen tubers growing in the *air*, in the axils of foliage-leaves? What happens if you cut off the underground tuber-bearing branches?

Cut across a tuber, and test for starch with iodine solution. Put a drop of water on a glass slide and dip a cut piece of tuber into the water: notice the small white starch-grains which escape from the opened-up cells of the tuber and become suspended in the water. If you have a microscope, examine the grains, some of which will show delicate lines corresponding to thin layers built up around the first-formed portion of the grain (Fig. 87). Do the lines run evenly around the centre of the grain, or are they closer together at one end?

These starch-grains are formed from sugar, by the activity of small colourless protoplasmic bodies called leucoplasts, distinguished from the *chloroplasts* found in green parts by containing no chlorophyll and

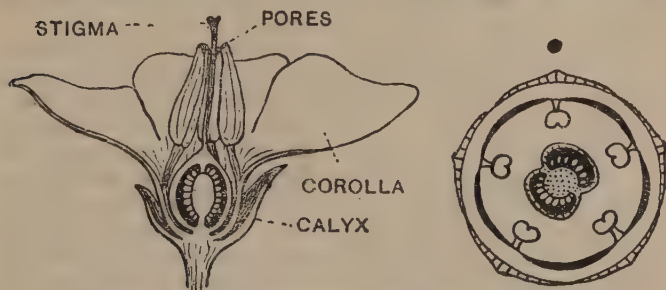


Fig. 88.—Longitudinal Section and Floral Diagram of Flower of Potato.

by being unable to build up sugar and starch from carbonic acid. Compare the results given with the iodine test in very young and small tubers with the starch-content of larger tubers. Compare the taste of (1) very young tubers, (2) fully developed tubers, (3) tubers which have sprouted and given out well-grown shoots. Test tubers in these different stages for sugar with Fehling's solution. Does the tuber contain any other kind of reserve-food besides starch? Shave off a very thin slice from the outer portion of a tuber and test it with iodine: the outer layer contains *proteids*. Note the layer of *cork* which forms a skin over the tuber; if this is shaved off, a new layer is formed. What is the use of the corky skin?

Note the arrangement of the leaves on the stem of the Potato-plant. Are the leaves simple or compound, with stipules or without? What peculiarity do you notice in the sizes of the leaflets in each leaf? The branching of the shoot, especially in the upper part, is rather complex; in most plants of the Potato family the branches and inflorescences do not arise strictly in the leaf-axils.

Examine the flowers (Fig. 88), arranged in more or less "flat-topped" inflorescences; the short calyx-tube with five sepals; the five-lobed funnel-like corolla; the five stamens with very short stalks and long yellow anthers, which taper and are joined above and open by pores at the top; the two-chambered ovary with numerous ovules, slender style, blunt stigma. There is no honey, but the flowers, by their coloured or white corolla, attract various kinds of insects, which come for pollen. Note the drooping of the flowers: do you see how this is advantageous in protecting the pollen from rain and in sprinkling the pollen over the bodies of insect-visitors?

Examine fruits of different ages. Does the fruit change in colour as it ripens? What other part of the flower remains after the fruit has formed? Cut across the fruit and note its structure. It is a true berry, for the whole of the ovary-wall becomes juicy except the firm outer skin; the only hard parts are the seed-coats.

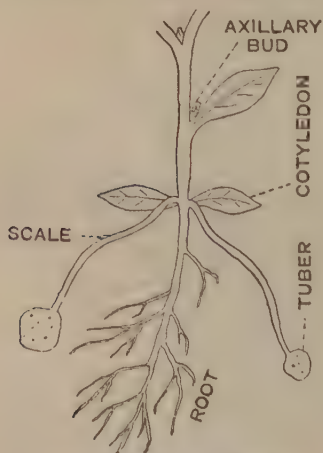


Fig. 89.—Seedling of Potato with Developing Tubers.

Compare a typical berry like this with the *pome* (fleshy part = receptacle-cup) of Hawthorn, Apple, Pear, and several other Rosaceae, and with the *drupe* (hard part = inner layer of ovary-wall) of Plum, Cherry, Blackberry. Compare the fruits of Plum and Date: the latter is a berry, because the "stone" is part of the seed (endosperm) and is *not* formed from the ovary wall. In a berry formed from an *inferior* ovary, e.g. Gooseberry, Vegetable Marrow, the outer

part of the ovary-wall, and therefore of the fruit-wall (*pericarp*), is of course formed by the adherent receptacle-cup, but it is pedantic to distinguish (at least in elementary study) these "inferior" fruits from "superior" fruits such as the Potato-berry. It is hardly necessary to point out that the term "seed" popularly applied to potato-tubers used in raising crops is quite wrong: the only seeds are those formed in the fruit. Why are Potatoes so seldom grown from seed? Fig. 89 is a diagram of a Potato seedling, showing two tubers on branches arising in the axils of the cotyledons.

278. Bittersweet Nightshade (*Solanum dulcamara*) is a woody perennial plant, forming a bush which usually straggles or climbs over other plants, especially in moist or shaded places. It is often many feet long, but it dies far back in winter.

The twigs are yellowish-grey in colour and bear conspicuous lenticels. The resting-buds have no special bud-scales; only two or three of the young leaves are visible from the outside. The rind (cortex) is bitter, the wood sweet. The leaves are stalked, the leaf-blade usually entire and egg-like or heart-like in outline, with a pointed tip, but the shape varies a good deal on the same plant, some of the leaves being lobed at the base, or even divided into three leaflets.

The flowers (June, July) have much the same arrangement and structure as those of Potato. Each flower has a slender drooping stalk; a short calyx-tube with five broad blunt lobes; a short corolla-tube with five horizontally-spreading lobes (each lobe purple, with two green spots at the base); stamens and pistil as in Potato. How does the fruit (ripe in September) agree with, and differ from, that of Potato?

Note the way in which the Bittersweet climbs. Does it twine its stems round the supporting plants, or does it merely insinuate its branches among them? Is the stem twisted? If twining occurs, is it always right-handed or left-handed, or in either direction indifferently? The Bittersweet is a feeble climber, as a rule. It is worth while to plant cuttings or grow seedlings and make experiments like those given for Scarlet Runner (Art. 249). Several foreign shrubby *Solanums* are often grown, some being erect plants, while others—e.g. *S. jasminoides*—climb by twisting their petioles around the support; other plants with "petiole-tendrils" are Clematis and Garden Nasturtium (*Tropaeolum*).

There are few native British representatives of the Potato family (*Solanaceae*) besides the Bittersweet (see Appendix III.). The Black Solanum (*S. nigrum*) is a very common weed, with small white flowers and a black berry. There are several plants, not belonging to *Solanaceae*, which might possibly be confused with Bittersweet in the absence of the flowers. The Clematis (Traveller's-joy, Old Man's Beard) is easily distinguished by its compound leaves with three leaflets; its twining petioles which persist round the support and turn thick and woody; its flowers, with five free whitish sepals, no petals, numerous stamens, and numerous carpels; its akenes, each with long hairy style; it belongs to *Ranunculaceae*. The Black Bryony (*Tamus communis*) is also a woody twining plant, with glossy dark-green heart-shaped leaves, and its fruits are berries, but its flowers are small and unisexual (male and female on different plants); while the White or Red Bryony is a relative of the Cucumber and Vegetable Marrow and has long tendrils.

279. Cleavers or Goosegrass (*Galium aparine*), belonging to the Bedstraw family (*Rubiaceae*), is very common in hedges.

The seedlings (seen in September or October, at least in south England) have large green oval cotyledons, and at first the young shoot grows erect. The stem is four-sided, and even the earliest leaves are arranged in whorls or circles, at first about four in each whorl, but later from six to nine. Get a plant and carefully examine the shoot, noting the small prickles on stem and leaves. Are the prickles straight or curved? In what direction do they curve, and why? Are they scattered evenly all over the surface of stem and leaves? Sketch a piece of stem, showing the arrangement of the prickles.

Do you think *all* the organs in each whorl are really leaves? Do they all bear buds or branches in their axils? if not, how many do so? Notice that in successive whorls the pairs of true leaves are at right angles. The other appendages in each whorl are apparently leaf-like stipules. There are always two true leaves (distinguished by the axillary buds or branches), and the number of other parts in the whorl depends on the extent to which the stipules branch on one hand, or "fuse" (grow together) on the other. Can you see what advantages the Goosegrass secures by this peculiar arrangement of the organs in circles? In thinking this question out, remember that the plant is annual, that all the organs are flat and green, and therefore need

plenty of air and light, and that they all bear the backwardly directed hooks. Notice how the Goosegrass-shoots insinuate themselves between the branches and leaves of the hedge-plants; why are the circles of organs separated by long "internodes" of stem at some points and by shorter "internodes" at other points on the same shoot?

One often sees the seedlings growing in crowded patches, some right below the hedge, others out in the open: which seedlings perish soonest, and why? The Goosegrass is one of the most interesting and instructive plants found in our hedgerows, and careful observations, at frequent intervals, of patches of its seedlings will give you a fine example of the fierce struggle for existence, which is naturally keenest in places like hedgerows (why?), and of the advantages (and disadvantages) accruing to a plant which is adapted to a special mode of life, such as the climbing habit. Note the enormous extent to which a plant grows in a single season. Trace a plant downwards and dig up its root: why is the root so long in the Goosegrass?

Note the numerous small white flowers, borne in clusters on slender branches; the star-like four-lobed corolla; four stamens alternating with the corolla-lobes; the inferior ovary, crowned by the minute sepals. Why are the flowers produced in such large numbers? By what kinds of insects are they visited? There is a flat honey-disc; the anthers and stigmas mature simultaneously, so that self-pollination may occur.

Note the dry two-lobed fruits, covered with hooks, which probably serve, now and then, to disperse the fruits by becoming attached to the clothing of animals and man, to loaded carts, etc. They are doubtless also carried by the wind, or fall off attached to leaves of Hawthorn and other hedgerow-forming plants.

Dissect the fruit, cutting it through in different planes and removing the fruit-wall, to see the curved embryo in the seed. Examine and sketch stages in germination.

QUESTIONS ON CHAPTER XIII.

1. Describe the foliage-leaf of a Potato-plant. Can you explain any advantage in having alternate pairs of large and of small leaflets?

2. Describe the tuber of a Potato, following the stages in its development up to the time when it is dug up for use as food.

3. Describe the structure of a fully grown and freshly dug-up Potato-tuber. Why is the tuber called (rightly) a stem-structure, not a root?

4. Describe the flower and fruit of a Potato. What are the chief peculiarities of the stamens? What other plants have similar stamens?

5. Describe the appearance of the shoots arising from (a) a Potato-tuber kept in darkness, supplied well with water; (b) a tuber exposed to light and well watered; (c) a tuber exposed to light, but *not* supplied with water.

6. In what places would you look for the Bittersweet? Describe its mode of growth, and compare it with that of a Scarlet Runner, Hop, or Convolvulus.

7. Describe the flowers and fruits of Bittersweet and compare them with those of Potato.

8. Describe the seedling of Goosegrass, with sketches of different stages in its growth.

9. Describe the way in which Goosegrass climbs. Why is this plant often called "Cleavers"?

10. Describe the shoot of Goosegrass, with a sketch. How can you tell which of the whorled structures are true leaves? How are the true leaves arranged on the stem?

11. Describe the flowers of Goosegrass, with sketches. By what insects are they pollinated?

12. Describe the fruits of Goosegrass, with sketches. How are they dispersed?

CHAPTER XIV.

DANDELION, DAISY, COLTSFOOT.

280. Dandelion (*Taraxacum dens-leonis*) is one of the commonest and most familiar of plants. It is apt to be confused with Hawkweeds and other allied plants of the same family, but is distinguished by the lobing of its leaves, and by its solitary head of flowers being carried on a soft hollow stalk which arises from the centre of the leaf-rosette.

Examine and compare plants growing in different situations, *e.g.* in exposed and in sheltered places, among short grass on a lawn, among longer grass in meadows, neglected lawns, or garden borders, in hard or gravelly soil and in soft damp soil. Note that the leaves have a strong tendency to spread out in a rosette and press themselves to the soil (what happens if you carefully dig up a plant growing at the bottom of a wall and put it into level soil?), but that among long grass the leaves grow up in a nearly vertical position.

Note the peculiar form of the leaves, which vary in the extent of the lobing and the shape of the lobes. Why is the possession of lobed leaves an advantage to a short-stemmed rosette-forming plant? Note how the lobes of the different leaves fit together with very little overlapping. Note also how rain-water falling on the leaves runs down the midrib to the tap-root, in which is stored the food that enables the plant to live from year to year. The Dandelion is really an evergreen plant, since it is never without leaves.

In a dug-up plant note the long tap-root, which is usually blackish outside and white inside; cut across the root of a plant and note that soon a healing-tissue ("callus") forms

over the cut surface, from which arise new shoots. It is not easy to tell, by inspection, where root ends and stem begins; the stem remains very short, covered by the leaf-bases, and each year it produces a bud for the shoot's further growth, while the root contracts (as in so many other "ground-hugging" plants, *e.g.* plants with runners, rosette-forming short stems, underground stems, bulbs, corms, or thick food-storing tap-roots) and draws the stem down so that it never comes above the soil. What do you suppose is the use of the bitter juice contained in the Dandelion tap-root along with the reserve-food?

The flowers, which appear in early summer but may be found (in south England and in sheltered places elsewhere) all the year round, are in solitary heads, each head on a long or short stalk. The stalk is smooth and hollow; when cut it gives milky bitter juice (also found in other parts of the plant) which turns brown on exposure to the air. Note the numerous (100 to 300, or even more) small flowers crowded on the flat expanded circular top (about 1 inch diameter) of the flowering stem or axis, each flower being inserted by a short slender base in a small pit. Where are the youngest flowers—at the centre or at the outside of the disc? By comparing heads of different ages you will find that the flowers open successively from outside to centre, so that the head resembles an umbel (*e.g.* Cowslip, Ivy) in which the flowers have no stalks (or very short ones) and are seated on the disc-like end of the flowering axis. Note the double circle (*involucre*) of narrow green leaves (*bracts*) around the head.

How do the outer bracts differ from the inner ones in form, position, and function? Does either series appear to perform any function *besides* that of protecting the very young flower-head before any of the flowers open or the flowering-axis grows up? Why does the inner series remain erect, though the outer bracts bend downwards?

In an open flower (Fig. 90) note the narrow strap-like outgrowth from the outer side of the mouth of the corolla-tube. How many teeth are there at the top of the strap? Now examine the flower carefully with your lens. Note the slender style, divided at the top into two curled branches (stigmatic arms), each about 2 mm. ($\frac{1}{12}$ inch) long, with

short hairs (in about 12 rows) on the inner (stigmatic) surface; note the long hairs on the style a little below the point of branching. Slit down the corolla-tube and trace the style down to the bottom of the tube; on its way down, the style passes through a tube about $\frac{1}{8}$ inch long; catch hold of the top of the style and pull it out of this narrow tube. What is this tube around the style? Can you see five slender threads joining the lower edge of this tube to the inner surface of the corolla-tube? If so, you should be able to see that the tube consists of the five anthers joined together by their sides. You remember that in Violet and Pansy the anthers are very close together, and that in Potato and Bittersweet they are joined at the top; here they are completely united, but still their outlines can be seen on careful inspection.

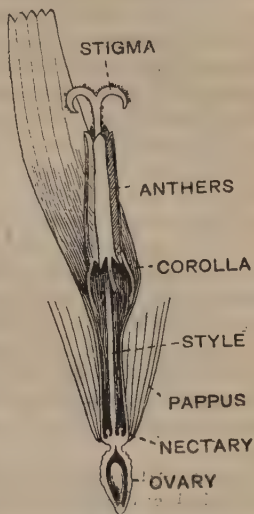


Fig. 90.—Flower of Dandelion: lower part (corolla-tube and ovary) cut open.

What is the swelling below the base of the corolla-tube? What do the hairs which form a circle just above this swelling? Can you see a slender neck-like part between the swelling (ovary) and the ring of hairs (*pappus*, representing the calyx)? Can you see the small ring-like cushion (nectary) at the bottom of the corolla-tube, around the base of the style? If you cannot make out all these points in the structure of the flower at the first try, examine more flowers until you succeed in seeing all the parts. The honey rises in the narrow corolla-tube, so that even short-tongued insects can reach it. The heads are visited by an unusually large variety of insects, including hive-bees, humble-bees, hover-flies, beetles, and butterflies.

The Dandelion is a very suitable plant on which to make daily observations with a view to learning the complete life-story of the flower-head and of the individual flowers. By

watching the same head at frequent intervals day by day, and by examining flowers of different ages, you can make out a good deal of the story for yourself. Is the head always expanded? Under what conditions does it close? Note how the straps of the outer flowers close over the inner flowers, and how the closing is completed by the inner circle of bracts. Does it close at night only? For how many hours does it remain open each day in fine weather? Do *all* the flowers in a head open on the first day that the head itself is expanded? How often must the head open in order that all the flowers in it may have a chance of being pollinated by insects?

Watching many Dandelion-heads in a garden, I have noticed that, as an average, the heads are only open for about eight hours on fine days and that a head rarely opens more than thrice. In fine weather nearly all the flowers in a head are open by the end of the third day, and on the fourth or fifth day the head is closed and the corollas are beginning to wither, while on cold and wet days the heads remain closed. How do these observations agree with your own?

Open up flowers of different ages, and note that at first the style is low down in the tube formed by the united anthers, the two stigmatic arms being in close contact by their inner (stigmatic) surfaces; the pollen is shed inside the tube, and is swept out of the top by the hairs on the style as the latter grows up. During this "male" stage, insects visiting the head remove the pollen-mass from the top of the anther-tube as it is pushed up by the piston-like style, and since the stigmatic surfaces are not exposed, only cross-pollination is possible. Then the style emerges and its two lobes diverge, exposing the stigmas; if cross-pollination does not occur during this second or "female" stage, the arms curve back until the stigmas touch the pollen still adhering to the style, thus bringing about self-pollination.

After the corollas have withered and the head has closed up for the ripening of the fruits, another interesting series of changes takes place. What changes do you observe in (1) the length of the head-stalk, (2) the shape of the expanded top of the stalk (which is at first *flat*), (3) the size of the ovary, (4) the length of the slender stalk (at first *very* short)

just above the ovary, (5) the ring of hairs at the base of the (now withered) corolla-tube? What becomes of the upper parts of the flower (corolla, stamens, style)? Does the head still open on fine days, or does it remain closed and for how many days? How is the change in form of the stalk-top connected with the change in form of the whole head? The "disc" is now becoming rounded (convex) instead of flat, while the fruiting head becomes a globular mass about two inches in diameter; the flat fruits require, therefore, to be spaced out on the "disc."

Do *all* the flowers in a head grow into fruits? Do you notice any difference in this respect between plants growing in sunny places and plants growing in shaded places? Why do the latter usually produce a smaller proportion of fruits than the former? Why are most of the unfertilised flowers usually found at the *outside* of the head? Probably the last three questions can be answered after considering the facts that efficient insect-visits are far more frequent (1) in sunny places and (2) in the more fully expanded and therefore more conspicuous heads, *i.e.* on the second and third days on which the heads are open.

These observations raise the question, is self-pollination an effective substitute for cross-pollination? I have tried experiments, designed to prevent insect-visits, with rather variable results, but on the whole the output of normal fruits has been much smaller than in neighbouring heads left untouched. Tie small bags of muslin or, better, paper over young unopened heads, and see how many fully developed fruits are produced. In watching Dandelion heads and noting all that happened day by day I have found that the average time from the first opening of the flowering head to the final opening of the fruiting head (with fruits ready for dispersal) is about eighteen days; it is lengthened a little by rainy days, shortened when the weather is fine. However, in this, as in all other readily verified matters, make your own observations instead of merely accepting those of other people.

Note the structure of the ripe fruit (akene), opening up the fruit-wall to see the single seed. Note how the parachute-like pappus (ring of hairs) closes up on wet days (why?) and expands on dry days (why?). By what agency is the seed dispersed? Try the effect of picking off the parachute

from the fruit; note the times taken for (1) a complete fruit with expanded pappus, (2) the same fruit deprived of the pappus, to fall from the same height. Try the comparison under different conditions, *e.g.* indoors, outdoors on a still day, outdoors on a windy day. Note the small stiff hairs (straight or hooked?) on the akene itself. How do these hairs help the akene to become attached to the soil after the parachute comes down? What are the advantages of having the pappus carried up on a long stalk? When is this stalk above the ovary developed? Is there any trace of it in the flower?

231. Daisy (*Bellis perennis*).—This familiar plant flowers from spring to autumn; even in winter a few days of sunshine will often cause the flower-buds to open. It is practically evergreen as well as perennial, producing leaves throughout the year. In general habit it resembles the Dandelion, but the stem is longer and it sends out runners all round, giving rise to numerous new plants; apart from seeds, therefore, the Daisy has a very efficient method of spreading and multiplying.

Carefully examine patches of Daisies at frequent intervals during the year, making notes (with sketches) of your observations. At what time of year are the "runners" given off by the parent plant most copiously? How many young plants may be formed in this way? How long are the runners?

Note the arrangement of the leaves in a rosette. Sketch a plant from above, showing the shapes of all the leaves. Where is each leaf broadest? What are the advantages of the peculiar shape of a Daisy leaf? Which leaves (upper or lower) have the longest basal parts and the largest blades, and why? Why is it a good plan for a rosette-forming plant to have its leaves broadest towards their free ends?

Examine the flower-heads (Fig. 91) and the individual flowers very carefully, on the lines indicated in the preceding article on the Dandelion. How long are the flowering-axes? How broad are the heads? Note the shape of the expanded top of the head (slice it down longitudinally) and the structure of the involucre (number of bracts? in how many circles? shape and colour of bracts?).

You will notice that the outer flowers, forming a single series, resemble those of the Dandelion in having a strap-like outgrowth from the mouth of the corolla, while all the inner flowers have a tubular corolla; the strap-like (*ligulate*) flowers are often called the ray-flowers, the small tubular ones the disc-flowers. Compare a ray-flower of Daisy with a Dandelion flower: note the shape of the strap, the narrow

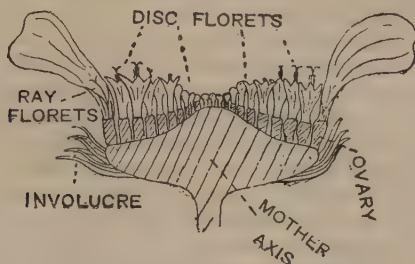


Fig. 91.—Vertical Section of Capitulum.

but short stigmatic arms, the absence of stamens. In a disc-flower note the regular tubular corolla, with five (sometimes only four) equal lobes round its edge, the thick short stigmatic arms, the presence of stamens. The ray-flowers thus differ from the disc-flowers in having no stamens, as well as in the shape of the corolla. In what respect do all the flowers differ from those of Dandelion?

Note the closing of the head at night and in bad weather. On a bright day the straps of the ray-flowers spread out horizontally, at night they move inwards and meet at the tops so as to cover and protect the young central flowers.

Is it possible to make the head close in the daytime? Cover a plant with a flower-pot or box, excluding all light by sprinkling soil round the edges where the pot or box rests on the ground. Keep a Daisy in darkness for two or three days, then bring it to the light, or remove the pot or box covering it; note that the head does not open completely, but remains half closed, as is also the case on dull days. Regular *alter-nation* of light and darkness is essential for the regular opening and closing of the heads.

How are the opening and closing movements affected by

changes in temperature? Pick a head which has closed for the night, set it in a bottle of water, and bring into a warm room: a temperature of 15°C . or even more will fail to cause opening. A Daisy head when closed in the evening does not readily open with even a considerable rise of temperature; when open in the morning it does not close unless the temperature is greatly lowered. If a closed head is warmed in the morning it readily opens; if an open head is cooled in the evening it readily closes.

Note the elongation of the convex top of the flowering-axis after the flowers have been fertilised, and the flat akenes without a pappus. The compressed akenes are doubtless carried by the wind, though very poorly adapted for wind-dispersal as compared with Dandelion fruits. However, in comparing the equipment of plants for the struggle for existence, one must not fix on any single biological advantage, but take into consideration the whole equipment. The akenes of Daisy cannot be so often carried to a distance as those of Dandelion, but once a Daisy plant establishes itself in a suitable place it may, by its runners, give rise to hundreds of plants in a few years.

282. Coltsfoot (*Tussilago farfara*) is a well-known plant whose flowering shoots appear early in spring (sometimes as early as December), long before the large leaves. The plants grow chiefly in damp heavy soils, in waste places or roadsides, in clayey fields—usually in well-exposed situations.

Note the yellow flower-heads (1 to $1\frac{1}{2}$ ins. diameter), each carried on a stem (4 ins. to 1 ft. high) which arises direct from the ground and at first droops but later becomes straight. The flowering-stem bears numerous scales which are, like the stem itself, covered with woolly hairs. At the top of the stem, just below the head, there are several short scales, then a series of long narrow bracts surrounding the flowers. Are the flowers all alike, with tubular or strap-shaped corollas? How many ray-flowers are there? How do they (1) resemble, (2) differ from, those of the Daisy and Dandelion? Is there any pappus? How many disc-flowers are there in the head? Does the style bear diverging stigmatic arms, or not? By careful observation try to make out the life-history of the flower-head.

The central (disc) flowers appear to resemble those of the Daisy, but close inspection shows that they are really *male* flowers, for the style acts merely as a piston to push the pollen out of the anther-tube; the style does not divide into two stigmatic arms. The outer (ray) flowers are *female* flowers, as in Daisy; both kinds of flower have a pappus, but it remains small in the male flowers, though it enlarges to form a parachute on the fertilised ovary of the female flower. Only the male flowers produce honey; insects visiting a newly opened head must (if cross-pollination occurs) bring pollen from an *older* flower (why?). When the head closes in the evening the pollen pushed out of the anther-tubes of the male (disc) flowers may be transferred to the straps of the female (ray) flowers, and when the head opens again the pollen may slide down the straps to the stigmas situated at the base, bringing about pollination.

Examine the leaves, which come up in a tuft, a few weeks after the flower-heads. The leaves are upright and rolled up at first, but when the blade begins to unfold it turns over so as to be horizontal, and then rapidly spreads out and becomes from three inches to nearly a foot broad. The leaf is covered, especially on the lower side of the heart-shaped angular blade, with a cotton-like mass of hairs (formerly soaked in saltpetre and used as tinder); the stalk is long and stout, and the fully grown leaf spreads out like an umbrella and stops the growth of other smaller plants below it.

Dig up a plant in early summer and note that each flowering shoot comes off independently from the stem, which bears the scars of the leaves of former years. In plants dug up in autumn note the young leaves for next year, also the egg-shaped buds of the flowering shoots, in which the young flowers can be plainly seen on making a longitudinal section. Note also the long white tough runners which arise from the stem and which enable the plant to spread over a large area. The Coltsfoot is a rampant and troublesome weed when once it gets a footing in fields, owing to its rapid spread by means of the runners and to its very effective method of choking off competing plants by its large leaves.

†283. **The Composite Family (Compositae)** is the largest among flowering plants, and one of the most successful and

widely distributed. It is easy to see why this family is such an aggressive and successful one. What are the advantages of having (1) numerous small flowers grouped together in a compact flat-topped head, (2) the outer flowers often more conspicuous than the inner ones, (3) honey in most cases accessible to even short-tongued insects, (4) in most cases small light fruits provided with a pappus?

Examine all the Composites you meet with and find out all you can about the arrangement and structure of the heads and of the individual flowers. How do the heads and flowers of Cornflower and Knapweed ("Hard-heads") differ from those of our three types? What other Composites resemble (1) the Dandelion in having all the flowers ligulate, (2) the Daisy in having the outer flowers ligulate and the inner ones tubular, (3) the Cornflower ("Bluebottle") and Knapweed in having all the flowers tubular? How do the outer flowers of the Cornflower-head differ from the inner ones? What common Composites have small heads densely massed together to form a flat-topped corymb of heads, and what are the advantages of this arrangement? In each case study the biology of the inflorescence and of the individual flower, in the way we have studied the Dandelion and Daisy.

In studying garden Composites note the small leaves (bracts) on the top of the head, among the flowers, in Sunflower and Dahlia, one bract on the outer side of each flower. Compare "single" and "double" Dahlias and Asters: how does the flower-head become "double"? Watch the various insects which visit the flowers of wild and garden Composites: why is there such a variety of visitors to flower-heads like those of Michaelmas Daisy? Groundsel, which flowers nearly all the year round, is said to be chiefly self-pollinated: test this statement by experiment. Wormwood (*Artemisia*) is said to be wind-pollinated: examine its flowers carefully and note the adaptations to wind-pollination.

QUESTIONS ON CHAPTER XIV.

1. Describe the vegetative organs (root, stem, leaves) of a Dandelion. Why is this plant a troublesome weed in lawns?

2. Describe the arrangement and shape of the leaves of a Dandelion. What differences in the leaves have you noticed in plants growing in diverse habitats, and how may these differences be explained?

3. Describe the structure of the flower-head of a Dandelion. Why is it wrong to call the head a flower?

4. Describe the structure of a single Dandelion flower, and relate any observations and experiments you have made on its biology, stage by stage.

5. Give a general account of the life history of a Dandelion flower-head as seen by watching the same plant day by day from the time it is first visible. How often did the head open and close? For how long did it remain open during a single day? Did it open every day—if not, on what sort of day did it (a) open, (b) remain closed?

6. Describe, from your own work, the adaptations of the flowers of Dandelion for cross-pollination by insects. Is there any provision for self-pollination? If so, explain the mechanism, with a series of sketches (from the actual plant).

7. Describe the way in which a Daisy spreads over a lawn. Compare it in this respect with the Dandelion. How many young plants have you observed in course of formation by the parent plant? Why do you suppose the Daisy resorts to this method of spreading apart from seeds?

8. Compare the flower-heads and flowers of Daisy with those of Dandelion. Which plant seems, from your own observations, to propagate itself most freely by *seed*?

9. In how far may a Daisy flower-head be compared with a flower?

10. In what sort of locality, and in what sort of soil, have you seen Coltsfoot growing? How does Coltsfoot spread (apart from seeds) and what makes it a tiresome weed in fields?

11. Describe carefully the appearances presented by a Coltsfoot plant month by month throughout the year: that is, give a brief "diary" of its year's life, noting such points as the time when the flower-head is first formed, when it emerges from the soil, when it opens, how long it remains open, when it closes again, when it re-opens to let the fruits escape, when the leaves emerge, how they expand, etc.

12. Describe fully the flower-head and flowers of Coltsfoot, and compare the pollination arrangements with those seen in Dandelion and Daisy.

13. Why are the Composites called "an aggressive and successful family"?

14. Write an account of the "division of labour" seen in the flower-heads of Daisy and Coltsfoot.

CHAPTER XV.

CROCUS, BLUEBELL, EARLY PURPLE ORCHID.

284. Crocus.—The life-history of Crocus should be carefully studied by continuous observation, according to the following detailed instructions. It is necessary to get the resting-corms* in *autumn*, because the buds which they bear do not keep fresh so long as those of most other "bulbous" plants.

Note that a dry resting-corm is almost entirely covered by brown **scales**, thin and dry. What can you see of the structure of the scales? Pull off a bit of this scaly covering: which surface (outer or inner) is rough and dull, and which is smooth and shiny? In which direction can the scales be torn easily, and why? Do the strings or fibres, of which the scales are almost entirely made up, run parallel, or do they diverge and form a network, or do they show both of these arrangements? What do you think the strings are, or at any rate were at one time?

Now look at the flat or concave lower end of the "bulb" (how can you tell which is the lower end?) and notice the roughly circular patch. Unless you have examined Crocuses after they have been dug up when the growth of flowers and leaves had finished for the season, you cannot tell how this patch was formed. What can you see on the lower end of the "bulb," just outside of this patch? Sometimes one can plainly see numerous short slender white pointed projections in this part, arranged in a ring. If you can see these, you should be able to guess what they are.

* Common Spring-Crocuses, about 5d. per dozen (much cheaper if bought in larger quantities for class-work)

Now remove the scales carefully one by one, starting from the lowest. Notice that each scale goes right round the "bulb," and that on removing it you can see a brown line where the scale was attached (Fig. 92). What name might

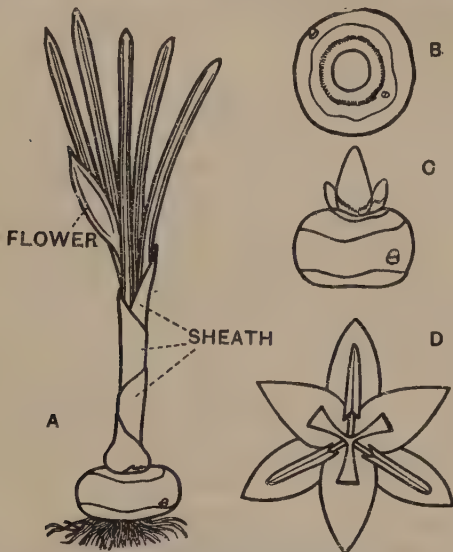


Fig. 92.—Crocus. A, Entire Plant just before the Flower has opened; B, Corm from below; C, Side view of Corm; D, Flower as seen from above.

be given to each of these lines? What name is given to the place where a seed breaks from its stalk, or a leaf from the stem? Would you call the hard white solid mass to which these scales are attached a **stem**? We know that a stem bears leaves and buds. As you remove the scales, notice that they become more crowded at the top, so that the scars are closer together here. What do you see projecting from this upper end? Can you find any similar projections lower down? In most cases you will find one between any two neighbouring scars. What are these projecting bodies?

From these observations you should be able to infer that the "bulb" is a short thick stem bearing **buds**. It is distinguished from most bulbs (Onion, Tulip, etc.) by having a

thick stem and thin dry scales instead of a very small stem and thick fleshy scales; it is therefore called a "solid bulb" or **corm**.

Now pick off one of the large buds from the top of the corm, and very carefully dissect it, making a sketch of the entire bud and of each part you remove from it. Notice first the **scales**: how many are there, how are they inserted (trace each one carefully to its base), how do they resemble the scales you picked off the corm itself, and how do they differ from these? Next notice the young yellowish or green **foliage-leaves**, each having a broad base inserted like a ring around the lower part of the bud; this part is not always easy to make out clearly, so you may have to try several buds.

What do you find in the centre of the bud? In most cases you will find one, two, or (in some Crocuses) more tapering, pear-shaped bodies covered by a papery sheath, and tapering to a point above and into a stalk below. Each of these bodies resembles a bud: what kind of bud can it be? Peel off the sheath: what do you find inside? This, then, is a **flower-bud**, containing a young flower. Notice the long tube ending above in six pointed oval lobes; the stamens (how many?), which are already very large as compared with the "petals"; the style, ending in three fan-like stigmas.

Now examine some Crocus plants in flower and in earlier stages of growth, or plant some corms in moist sawdust or soil (just as you did with seeds of the Broad Bean and other plants), and watch their growth. Notice the swelling and upward growth of the buds; the roots which spring from the base of the corm, arranged in a ring; the sheath, consisting of the enlarged bud-scales, which covers the young shoot until it has grown well above the surface of the soil; the bursting of the sheath and the appearance of the foliage-leaves, which are now bright green in colour; the escape of the flower from its sheath, which consists of two white membranous leaves (bracts).

Examine the flower carefully, noting and comparing what you see in flowers in different stages, or in the same flower day by day from the time of its emergence from its sheath. Note the six coloured lobes, three outer and three inner, which form the most conspicuous portion of the flower, and

which arise from a funnel-like structure, prolonged below into a long narrow tube. The tube, funnel, and lobes together form the *perianth*, this term being used when there is no clear distinction into calyx and corolla. But it would be simpler, and just as correct, to call the three outer lobes "sepals," the three inner ones "petals," and the tubular part the "flower-tube."

Note the three stamens, each consisting of a long anther (showing the four pollen-sacs very distinctly) and a short filament: the latter is inserted on the mouth of the flower-tube, opposite a "sepal," and the stamen is spear-shaped owing to the anther being produced into a sharp point on each side of its base (where the filament is attached). Note the three fan-like stigmas, with more or less toothed or frilled edges, continued below into the style; cut open the flower-tube and trace the slender style right down. Both the style and the flower-tube arise from the top of a swelling, the ovary; cut the ovary across and notice the numerous "young seeds" arranged in two longitudinal rows on the inner side of each of the three ovary-chambers. Below the ovary is the flower-stalk; the bracts spring from this stalk, just below the ovary.

Close observation of a flower day by day will show that the lobes spread out in the daytime and move inwards at night, thus causing the opening or closing of the flower. The flower opens when exposed to light, sufficient warmth, and dry air, whilst its closing may be caused by coldness or dampness of the air as well as by darkness. The movements of opening and closing can, by careful measurement, be shown to be caused by the outer sides of the perianth-lobes growing faster (closing movement) or more slowly (opening movement) than the inner sides. What are the advantages to the flower of this power of opening or closing? What other plants, growing wild or in gardens, have flowers which open on bright days and close on dull or wet days and at night? For how many days does a Crocus flower last?

It is easy to discover that the anthers open by two slits, shedding the pollen outwards, *i.e.* away from the centre of the flower, that this happens while the stigmas are in contact with each other, and that a day or two after the anthers have opened the three stigmas separate and spread out, one opposite

each *outer* perianth-lobe. Do you see how this helps in

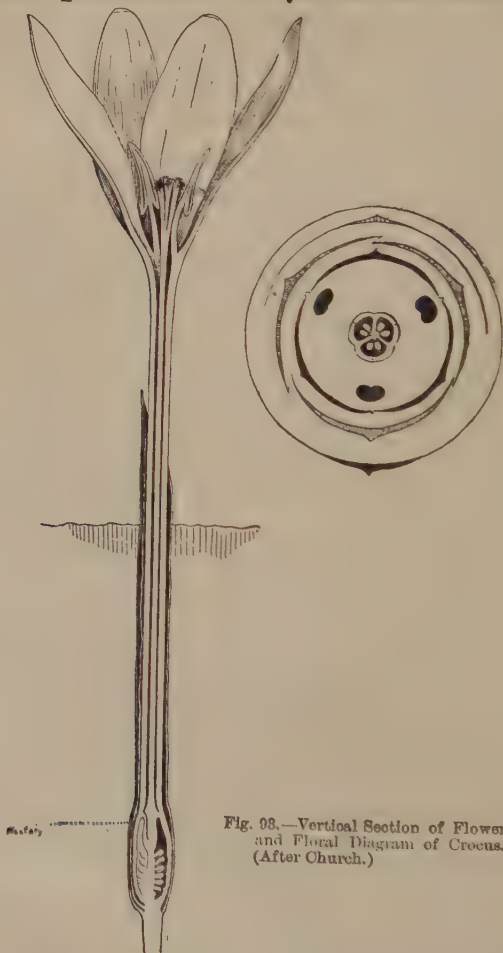


Fig. 98.—Vertical Section of Flower and Floral Diagram of Crocus. (After Church.)

promoting cross-pollination? The Crocus flowers are visited by bees, butterflies, and moths.

The Crocus contains honey in abundance, as can easily be seen by opening up the perianth-tube; the honey, produced by glands in the partitions between the three ovary-chambers, rises up the tube and can be sipped by bees entering the flower. The bee stands on the perianth-lobes and pushes its head into the funnel-like mouth of the tube, seeking for the honey, and in doing this it touches the stigmas (if these have spread out) and then the stamens. If, however, cross-pollination fails to occur, the stigmas may curl over and touch the anthers, bringing about self-pollination.

After the flowering period the perianth, stamens, stigmas, and style wither; if fertilisation has occurred the ovary grows larger and forms the fruit, which later on is carried upwards by the lengthening of the flower-stalk. The fruit (capsule) ripens about the end of June (in Spring Crocuses) and splits down the middle of each chamber, setting the seeds free (Fig. 94 A). The seeds, which are egg-shaped, contain a small

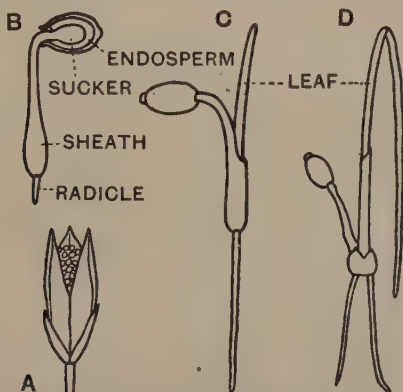


Fig. 94.—A, Capsule just opening; B, Seedling (seed cut open); C and D, Later Stages in Germination.

embryo. If sown when ripe, they germinate in the following spring. The tip of the cotyledon remains in the seed to digest and absorb the endosperm, while the rest of the young plant is pushed out by the growth of the lower part of the cotyledon; the radicle and plumule then escape from the swollen base of the cotyledon (Fig. 94). It takes two or

three years, however, before a flowering corm can be raised from seed. Note the thick roots formed by young corms: these contract and pull the corm into the soil.

Long after the flowers have withered the foliage leaves persist, carrying on photosynthesis and storing up food. Where, and in what form, is this food stored? Examine a Crocus plant in May or June, noting the swollen base of each shoot that has grown from a bud on the corm. The latter is now withered and shrunken, while the swollen shoot-bases are fresh and plump. Cut vertically through one of these swollen bases and note the solid white mass, which is obviously a *young corm*. The young corm is formed by the swelling of the base of the stem, and its cells contain food which has been made by the leaves and has travelled downwards for storage in the young corm. Of what nature is the stored food in the Crocus corm?

The new corms continue to grow in size until the foliage leaves die and wither, when they will be found to have become as large as the parent corm (to which they are attached) was when planted. Three or four, or even more, new corms may be developed in this way on the parent corm. Gardeners usually dig up Crocuses after the leaves have withered, and the young corms, which readily break off from the old withered corm, are stored in a dry place until the time comes for planting them. In this way the number of corms is multiplied, and in most cases gardeners do not trouble to raise Crocuses from seed. Hence by the formation of corms the Crocus is not only enabled to last from year to year, *i.e.* to become a *perennial* plant; the production of several new corms on each old one is a method of *vegetative multiplication*, *i.e.* increase apart from seeds.

Now we can explain certain features of the dry Crocus corm. What is the patch at the base of the corm? Simply the *scar* where it separated from its parent corm. The brown stringy scales are, of course, the withered bases of the bud-scales and the foliage leaves. However, compare carefully the parts of the fresh young corm with those of (1) a dry corm, (2) a bud on a dry corm, (3) a shoot which has grown from a bud.

Crocuses are divided into two groups according to the time of year when they produce their flowers. Some of the best known Spring-

flowering Crocuses (flowers February to beginning of April) are *Crocus aureus*, the Common "Dutch Yellow"; *C. susiannus*, the "Cloth of Gold"; *C. vernus* (flower white or purple, leaves ribless); *C. biflorus* (flowers white or lilac, leaves short erect narrow with white midrib). Among Autumn-flowering Crocuses are *C. nudiflorus* and *C. sativus* (Saffron Crocus); the latter is easily distinguished by its very large scarlet stigmas. Spring Crocuses should be planted in the garden in September or October, Autumn Crocuses in July.

285. Bluebell or Wild Hyacinth (*Scilla nutans*) is one of the most familiar of spring-flowering plants. It grows best in woods which are not *too* deeply shaded, but it sends up its leaves and flowers early in the year, thus gaining the benefit of the light and of insect-visits before too many other plants have joined in the competition. By the end of May, when the wood has become darker with the full foliage of the trees, the Bluebell has ceased flowering.

Note the long (9 to 18 ins.) and narrow (about $\frac{1}{2}$ in.) leaves; the flowering shoot which grows, as a rule, beyond the leaves; the bell-shaped perianth, the six parts of which are free, or joined only at the bases; the stamens, one inserted on the base of each perianth-leaf. Below each flower there are paired bracts, which help to pack up and protect the flowers in the bud-condition. Note the blue colour of bracts, perianth, filaments, and pistil. The latter consists of a ribbed ovary (cut it across and note the structure), style, and three-lobed stigma (the lobes are often very faintly marked). Honey is found along the grooves which run down the outside of the ovary; the nectaries or honey-producing glands are in the partitions between the three chambers of the ovary.

The flowers are sometimes pink or even white, instead of having the typical blue-purple colour. The flower-stalk is erect until the flower opens; then it bends down and the drooping flower is protected against rain, which would spoil the pollen and honey; finally, when the fruit is ripe the stalk curves upwards again, so that the seeds are shaken out gradually from the three slits into which the capsule opens. Visit plants at intervals, so as to observe all the changes which occur from the time the leaves and flowers emerge from the soil until the ripe capsule opens to let the seeds be scattered by the wind.

Dig up a few plants each time you visit a place where Bluebells grow; a useful plan is to thrust sticks into the

soil to mark the positions of the plants, so that you can get the underground parts after the leaves and flowering shoots have died down. "The Bluebell is a plant which carries on a considerable part of its activity underground. At all times of the year some work is going on, and although much of it is hidden from view, a study of this underground history constitutes one of the most interesting phases in the life-cycle of the plant."*

Examine the swollen lower portion of the shoot, which often lies about a foot below the surface of the soil. Tear off the thin outer scales (leaf-bases) which surround it, and note the white, sticky, fleshy scales which make up the greater part of the swollen mass. Cut (1) transverse and (2) longitudinal slices through this mass, and notice in the latter the small disc-like stem from which all the scales arise, and which bears roots on its lower surface and buds on its upper surface. This structure is a **bulb**. It differs from the corm of the Crocus (Art. 284) chiefly in the relatively smaller size of the stem, and in its investment by thick fleshy scales, which contain large stores of reserve food. In *scaly* bulbs (Lilies) the food-containing scales, of which the main bulk of the bulb is composed, simply overlap at their margins, whereas in *tunicated* bulbs (Bluebell, Onion, Hyacinth) the outer leaves are large and completely ensheath the inner portions of the bulb. The coloured membranous covering on the outside of such bulbs is formed by the shrivelled remains of the leaves of a previous season.

The bulb of a Garden Hyacinth, a Daffodil, and an Onion should be examined, since the parts are more easily observed than in the Bluebell. The bulb is largely composed of the enlarged persistent bases of foliage-leaves, but it also includes a certain number of scale-leaves. A bud arises in the axil of the innermost leaf, and next spring this will develop into a flowering axis, surrounded by a number of foliage-leaves, and outside of these a few scale-leaves. The outermost scales of the previous year shrivel, the inner ones persist, together with the bases of the foliage-leaves, and the enlarged axillary bud now forms the central portion of the new bulb. This may continue for several years, but ultimately two or more buds develop in the axils of the upper leaves. As they grow, they rupture the parent bulb, and are set free, after having absorbed a large amount of nourishment from it. This is

* Woodhead, "Notes on the Bluebell," *Naturalist*, 1904.

especially well seen in a *Narcissus* bulb. Buds, composed of scale-leaves enclosing foliage-leaves, may also develop in the axils of the outer scale-leaves.

We saw that the *Crocus* corm contains abundant starch: what reserve food is present in the *Bluebell* and these other bulbs? On testing a sliced bulb with iodine we find that the *Bluebell* contains very little starch, the *Onion* none at all. The chief food stored in the *Onion* is *sugar*, as can be proved by means of Fehling's test, while the *Bluebell* bulb contains chiefly a carbohydrate substance called *inulin*, which resembles starch in composition but is soluble in water (less so than most sugars, however).

The underground life-history of the *Bluebell* is very interesting, and the main points, as regards external features at any rate, are fairly easy to make out. Young seedlings can be dug up in October or November, older ones in May and June, but if you cannot find the seedlings in the soil bring some capsules home and sow the black globular seeds. The germination is similar to that of the *Onion* in many respects (Art. 104).

† The seed is endospermic, with a small embryo at one end; the cells of the endosperm contain proteid grains, and have thick walls (cellulose). The cotyledon is curved so as to form an incomplete tube around the young shoot. When germination begins this tube grows longer and pushes outwards and downwards, carrying with it the young shoot, which is embedded in the thickened base of the tube; the first foliage leaf grows up inside the tube, while the first root grows down into the soil. When the seedling is 2 or 3 inches long the first sign of the bulb is seen as a swelling just above the root.

In spring the foliage leaf grows into the air, becoming 5 or 6 inches long. The tip of the cotyledon remains in the seed to digest and absorb the endosperm; the contents and walls of the endosperm cells are acted on by ferments (secreted by the tip of the cotyledon), and finally nothing is left but the hard seed-coat. The lower part of the cotyledon forms the first scale-leaf of the young bulb; new roots are produced, the first root soon becoming withered; the first foliage-leaf remains active until summer, making food and storing it in its base. The new roots contract at their thickest parts, just below the young bulb, thus drawing the bulb down into the soil.

286. Early Purple Orchid (*Orchis mascula*).—This is the commonest and best known of British wild Orchids. It grows in various situations, most luxuriantly in low-lying or

sheltered and moist meadows, where its flowering shoot may reach a height of over a foot, while on exposed downs it is only a few inches high.

Note the strap-shaped leaves, which come up in a rosette along with, and surrounding, the inflorescence about the middle or end of April; each leaf clasps the stem at the base and usually has dark purplish spots or blotches.

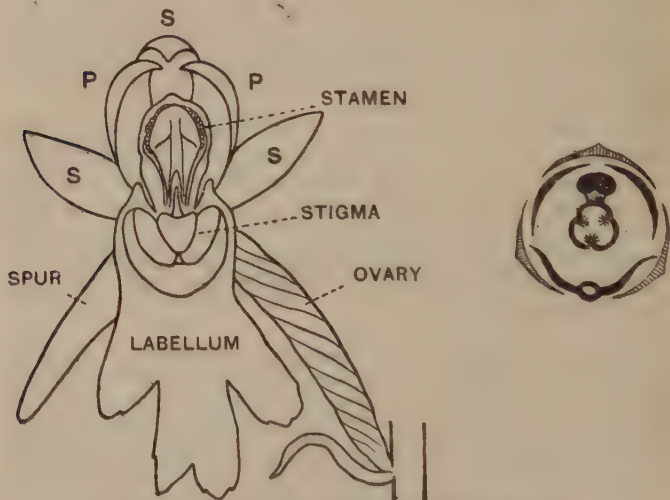


Fig. 95.—Flower (front view) and Floral Diagram of *Orchia*.

Examine the flowers, noting their spiral arrangement on the stem, the youngest ones being at the top. Note the bract below each flower (Fig. 95); the three sepals, alike in form and size; the three petals, one of which is larger than and different in shape from the other two. This large petal, the *labellum*, consists of a broad lip and a curved spur; it is rather like the spurred petal in a Violet, but it contains no liquid honey. The thick wall of the spur, however, consists of sweet tissue, as can be perceived by chewing it, and an insect can only get the sweet juice by scraping the inside of the spur.

The structure of the inner parts of the flower is rather complex, but the essential points for our purpose are easily made out. Do you see, above the mouth of the spur, a projecting mass consisting of two club-like structures, side by side, arched over by the two small petals and one of the sepals, and below these structures a rounded knob? By slicing the flower longitudinally, so that the slice passes down through the middle of this mass and the middle of the labellum, and by careful inspection, you will find that each of the club-shaped structures is a pocket which opens by a vertical slit and contains a greenish club-like body with a slender stalk, and that the stalks of these two bodies are joined below to a sticky disc resting on the rounded knob below. The green clubs are called *pollinia*, and the two together represent an anther, in each of whose lobes the pollen-grains are massed together into packets joined by elastic threads.

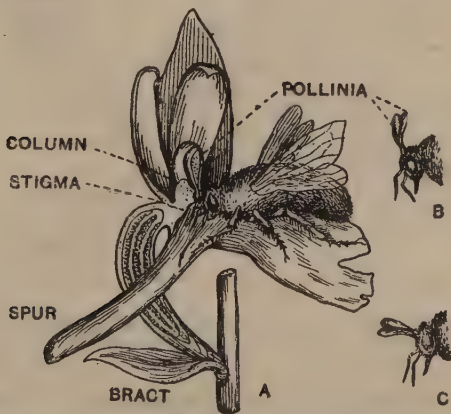


Fig. 96.—Pollination of Orchid by a Bee.

At C the pollinia have bent forward and will touch the stigma of the next flower visited.

The stamen and the style have grown up together, so that the stamen stands above the knob-like stigma. The rounded sticky disc (*glandula*) at the base of the pollinia lies in a small cup-like structure, just above the stigma. This cup

(*rostellum*) splits readily on the slightest touch—perhaps spontaneously—so as to expose the disc. A bee visiting the flower pushes its head against the disc as it pokes its tongue into the spur, and when it leaves the flower it carries off the pollinia planted on its head by means of the sticky disc. Then the disc contracts in such a way as to bring the pollinia downwards and pointing forwards, and the thick end of a pollinium touches the stigma of the next flower visited (Fig. 96 B, c), and the sticky stigma drags off some of the packets of pollen. The pollinia remain fixed on the bee's head, as the sticky disc soon hardens, so that a single pollinium may be carried about and pollinate several flowers before all the pollen is pulled off by the stigmas. One often sees a bee, which has been visiting Orchids, carrying a dozen pollinia stuck on its head, base of tongue, and thorax.

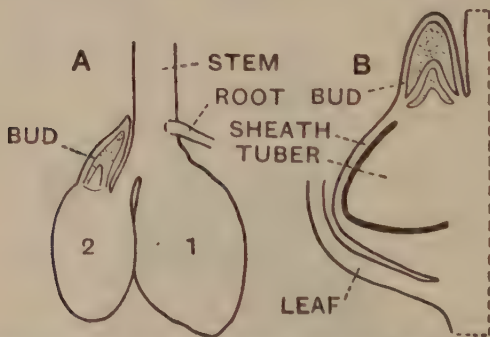


Fig. 97.—Orchis. A, Base of a Plant (dug up in summer), with old (1) and new (2) Tubers; B, Section of a developing Tuber.

Poke a pointed pencil into the spur of the labellum (to imitate the action of a bee thrusting in its tongue to scrape the honeyed walls of the spur). Notice the two club-shaped masses of pollen which are withdrawn from their pockets and remain attached to the pencil by the sticky mass at the base of their stalks. What change in position do the pollinia undergo after being removed, and how does this help in bringing about cross-pollination?

Where is the ovary? Examine the apparent stalk of the

flower, opening it up with a pin or the point of a knife. Note the three ovule-bearing strips (placentas) on the inner wall of the one-chambered ovary. The real stalk, at the base of the ovary, is very short: the long inferior ovary makes a long flower-stalk unnecessary, as it pushes out the flower and exposes it to visiting insects. A curious point is that the ovules are not formed until after pollination has taken place. Compare young and mature flowers to see the twisting of the ovary, which brings the labellum to the front.

Trace the shoot down, below the inflorescence and the leaves, to the basal swelling, which is a root-tuber. Cut the tuber across and test the cut surface for starch. Besides

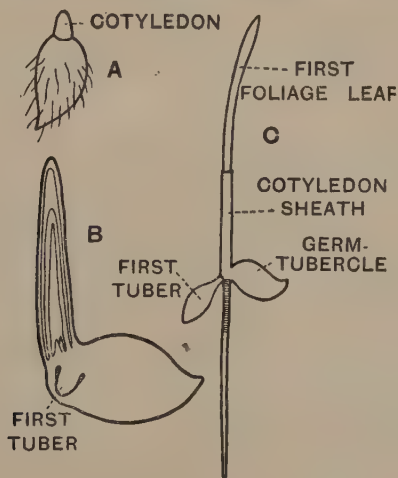


Fig. 98.—Orchis. A, Stage showing "Germ-tuber," bearing Root-hairs, with the Cotyledon above it; B, Section of a later Seedling, showing origin of first Root-tuber; C, A more advanced Seedling with first Foliage Leaf (note contraction of Root).

the tuber in which the present year's shoot ends, notice the brown and shrunken tuber formed last year, and the new tuber being formed for next year. To see these tubers of different ages and to trace their life-history you must of course examine plants at different times of year.

Each year one root (sometimes two), instead of growing out like the other roots, becomes swollen up and packed with food (made by the green leaves and transported downwards through the stem); this root is formed at the base of a bud, from which next year's leaf- and flower-bearing shoot will develop (Fig. 97). When the shoot dies, the root-tuber, with the bud above it, remains in the soil during winter, and the early growth of the shoot takes place at the expense of the food stored in the tuber, while ordinary roots grow out to absorb water and salts from the soil.

The fruit, a capsule, opens by three longitudinal slits; the seeds are very small (easily dispersed by wind), the embryo is minute and only slightly developed in the ripe seed. The germination of the seed is very similar in essentials to that described for the Bluebell; note the formation of the swollen "germ-tubercle" and of the first root-tuber (Fig. 98).

287. Notes on Spring-flowering Plants.—We have now studied several plants which flower in spring or early summer. You should write down a list of these spring-flowering plants, and others which you have observed and become acquainted with. Are these early-flowering plants perennials or annuals? Do you know of any *annual* spring-flowerers? There are a few such plants. On comparing and tabulating the spring-flowerers we have studied you will notice that they are perennials, that they store up food (in rhizomes, bulbs, corms, root-tubers, etc.), that many of them grow in woods or in hedgerows which later in the year are often densely shaded (by what?), that their flowers have means of protection (against what?) by closing-up or drooping. Note any other points that occur to you, and then try to account for the various peculiarities of spring-flowering plants. How are these plants enabled to flower so early?

"Many of the early flowers of spring in this country are garden flowers only. The Crocus and the Winter Aconite are great favourites, the former throughout the whole country, the latter in the south of England chiefly. They are both natives of south Europe, and, though occasionally found wild in Britain, their garden origin need never be doubted. Others, like the Snowdrop, the Daffodil, and the Sweet Violet, are chiefly seen in gardens, but sometimes occur in habitats that render their garden origin much more questionable. These species,

too, are at home in south Europe, and botanists are unable to agree as to whether they are really native in England or not. Others again are so abundant in hedgerows and woods that they are universally regarded as indigenous to this country, though widely cultivated in country gardens. Of this class the best known are the Primrose and the Bluebell.

"All the flowers hitherto mentioned, when in their native haunts, occur in shady woods, which are protected from the cold, the wind, and the snow. The milder woodland climate tempts these plants to flower early, before the shade of the leaf-canopy overhead cuts off their share of light. Insects, too, so necessary for the fertilisation of these flowers, forsake the woods, to a great extent, when they become densely shaded in summer. Flowering so early in the year, the plants must draw upon supplies of food made during the previous growing season and stored up underground, in bulbs, tubers, etc.

"Many shrubs and trees have spring flowers. The Hazel and the Alder may be said to engage in an annual race as to which shall be in flower the first. As a rule the Hazel wins. *Daphne*, a small shrub with purple flowers and a decided odour, is never long behind. The Yellow Jasmine, the Flowering Currant, and the *Laurustinus* are also largely planted in England, but they are all importations from the continent. The Elm and the Ash produce the dingiest-looking spring flowers of the whole plant world. The Wych Elm and the Ash are indigenous to Great Britain; but the common or 'English' Elm was originally introduced from south Europe. So, too, was the Almond, perhaps the most beautiful of the spring flowers in the south.

"Plants in south Europe have their period of active growth during our winter and spring, and their period of rest during our summer and autumn. In England the resting period of the native plants coincides with winter cold: in south Europe it coincides with summer drought. It is the summer drought and the winter rains of south Europe which cause the flowers of that region to appear so early in the year; and the plants appear to be quite unable to shake off the effects of heredity when they are transplanted to the colder climate of Britain. In the dark and dead of the British winter the shop windows of the florists are ablaze with *Narcissi*, *Violets*, *Daffodils*, *Anemones*, *Freesias*, and the like. It is again to the winter rains and high winter temperature of south Europe that we are in debt. Flower farms in the favoured regions of south France send us the first supplies of these choice blooms. A little later the growers of Brittany and Normandy enter into competition with those of the Channel Isles, the Scillies, and south-west Cornwall. These supplies exhausted, the cultivators of the home counties and the midlands send their later blossoms; so that it is now possible to purchase 'spring flowers' during the greater portion of the year."*

* Dr. C. E. Moss, *Certificate Examiner*, No. 31 (April 8th, 1908).

QUESTIONS ON CHAPTER XV.

1. Describe, with sketches, the structure of a resting *Crocus* corm.

2. Give a clear account, from your own observations, of the events which occur from the time a resting *Crocus* corm is placed in moist soil or sawdust, up to the time when the leaves die down. Include the changes that occur below as well as above the soil, and give a series of sketches.

3. For how many days does a *Crocus* flower last, from the time when it first opens?

4. Describe observations and experiments you have made on the opening and closing of the *Crocus* flower.

5. What other flowers with which you are familiar open and close like the *Crocus* flower?

6. Describe the structure of the flower of Bluebell, and compare it with that of a Garden Hyacinth.

7. What other flowers besides those of Bluebell droop when they open? How is the drooping caused? Can you explain why so many spring flowers either droop or have the power to open and close? Give a list of spring flowers which droop and of those which perform opening and closing movements.

8. Describe, from your own observations and dissections, the structure of a Garden Hyacinth bulb. Sketch, on a large scale (about twice the natural size), a longitudinal section made through the centre of a bulb, marking all the parts shown.

9. Describe and explain the structure of a *Narcissus* bulb, with the smaller bulbs attached to it. How is it that some scales go round the whole set of bulbs?

10. Describe carefully all you saw when growing a Hyacinth bulb in soil, sawdust, or water, and explain the things you saw. Give sketches.

11. Describe the whole of an Early Purple Orchid plant as seen when in flower in early summer, omitting the flowers themselves.

12. Describe, from your own observations, the growth of an Early Purple Orchid from the time when its leaves first come above ground until they die down. When did you first see the leaves, and when do they die down?

13. Describe, with sketches from actual specimens examined, the flower of the Early Orchid, and explain its adaptations for pollination. Describe experiments you have made with the flowers.

14. Compare the following plants with regard to the nature of their reserve food and that of the food-storing organs:—*Crocus*, Bluebell, Garden Hyacinth, White Lily, Orchid, Onion.

CHAPTER XVI.

WHEAT, OAT, BRITISH GRASSES.

288. Wheat (*Triticum vulgare*).—The origin of the cultivated varieties of Wheat is very uncertain, as in the case of the Broad Bean and other plants which have long been in cultivation. The closest relative of Wheat among British Grasses is Couch-grass, but Wheat is annual while Couch-grass (like the great majority of Grasses) is perennial.

We have already studied the germination of the Wheat grain (Art. 96). In a young plant showing four or five leaves note the arrangement of the leaves in two opposite rows, each leaf arising from a slight thickening ("node") on the stem. Note the narrow green leaf-blade, bearing green ridges, separated by white grooves, on its upper surface; in the early leaves there are about a dozen of these ridges. Note that the blade has no stalk, but passes into a sheath covered with soft hairs on the outside but smooth within; the sheath clasps the stem, but is split down on the side opposite the blade. Note the outgrowth, or upward continuation, of the sheath at the base of the blade; this outgrowth, here long and either rounded or toothed on its margin, is called the *ligule*. At each side of the base of the blade note the thread-like outgrowth (*auricle*).

Trace the leaf-sheath downwards to its insertion on the stem, noting the firm thickened basal part of the sheath, which produces the swelling at the "node," and the softness of the stem in this region. Examine plants at different stages of growth. In seedlings with only four or five spread-out leaves, on carefully pulling down each leaf-sheath, also on slicing the whole shoot longitudinally, you will notice

(1) a bud in the axil of each leaf, (2) a small swelling at the tip of the stem. Later on, note that the buds have grown out of the leaf-sheaths and given rise to branches, which may repeat the process. By this branching or "tillering" as many as fifty shoots may be produced from the basal part of a single Wheat plant. The swelling at the end of the stem will now show two opposite rows of projections—the young "ears."

In the ordinary kind of Wheat flowering occurs in June. At the beginning of May the "nodes" are still close together, so that although the leaf-blades are long and well developed the sheaths overlap each other. But now the "internodes" of the stem begin to lengthen, spacing out the leaves and carrying the shoot upwards. This elongation, which is most marked in the upper "internodes," is largely due to the active growth of the soft parts of stem just above

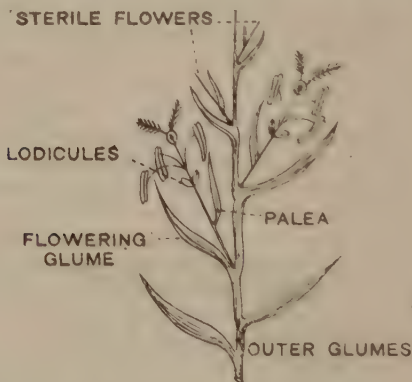


Fig. 99.—Diagram of a Grass Spikelet.

each node—the parts enclosed in the leaf-sheaths—though elongation also occurs in all parts of each "internode." Since the stem grows in width as well as in length, the inner tissue is torn and the stem becomes hollow, except at each node, where a solid partition remains. The growth in length is especially marked in the uppermost "internode" (above the highest leaf), which carries up the inflorescence or "spike."

About the beginning of June the sheath of the highest leaf swells up, owing to the growth of the "spike" which it encloses, and in about a fortnight the flowers are mature and the spike emerges from the sheath. The "ears" are arranged in two opposite rows; each ear is flat and is attached to the axis of the spike by its side, so that the whole spike is four-sided (the flat ears of Rye are attached by their *edges*, hence the Rye spike is flattened).

Examine a single ear and, beginning at the base, note the two lowest scales, nearly opposite each other, hard, dry; these **outer glumes** enclose from three to five flowers (usually three) arranged alternately on opposite sides of the ear (Fig. 99). In each flower (Fig. 100) note the two enclosing scales—an outer scale (*flowering glume*) which is similar to the outer glumes but sometimes bears a bristle (*awn*) at its tip, and an inner scale (*palea*) which is thinner. Within the palea come the three stamens and the pistil. The stamens when ripe have long filaments, the filament being attached to the middle of the anther; the pistil consists of a rounded ovary bearing two feathery stigmas. Note the two very small white scales, each with a fringed upper margin; these are called the **lodicules**.

Wheat, like other Grasses, shows several adaptations to wind-pollination, though (like most other cultivated cereals) it is largely self-pollinated. The spike is carried well up into the air; the pollen-grains are small and dry; the ripe anthers are pushed out of the flower by the elongation of the filaments and dangle about freely owing to their "versatile" (easily turned or swung) insertion on the end of the filament; the hairy styles expose a large surface to catch pollen-grains. Before flowering occurs plenty of food has been manufactured by the green leaves and stored up in all parts of the plant—leaves, stem, roots. The enormous extent of the root-system of a single Wheat plant makes it easy to



Fig. 100.—Flower of Wheat enclosed in its two Scaly Bracts or Glumes.

understand what a large amount of food can be stored in them, to be drawn upon for the maturing of the grains. The roots penetrate deeply into the soil, and since each of the "tillers"—branches arising from base of parent plant—produces scores of roots (especially from the lower "nodes") the aggregate length of the roots of a single plant runs to hundreds of yards.

"When the Wheat is in full bloom the active life of the plant as a manufacturer of food has reached its climax. The plant has attained its full size, all its leaves are spread out in the air, and the roots have gained their greatest dimensions in the soil. The building up of new tissues has ceased. The activity of the plant is now directed to utilising the surplus food (stored in leaves, stem, and roots) in the production of the seed. This will be more apparent if we consider the actual increase in weight of the dry matter of the plant, excluding the roots, at three stages in its life—the end of March, the end of June, and at harvest. Of the dry matter of the ripe plant 20% was present by the end of March, when some four leaves were visible; 45% was added by the time it was in full flower at the end of June; and the remaining 35% before harvest. This 35% is not, however, an addition to the weight of the plant by the production of new food; the greater part of it had already been prepared and had been sent down into the roots to be in store there until it was needed. When the flowering is finished it is transferred from the underground parts of the plant to be finally stored in the seed, and necessarily increases the weight of dry matter in the plant above ground."*

The stem or "straw" of the wheat plant is hardened by the fibrous tissue surrounding the bundles, which form a hollow cylinder, and additional strength is gained by the presence of flinty matter (silica) in the epidermis. The stem has alternate green and white lines, like the leaf, the green lines bearing stomates.

It is interesting to compare the strength of the "straw," which has to bear the weight of the heavy ripe spike, with that of other materials. Cut off ripe spikes and attach them (tie with thread, or stick with sealing-wax) to wires of steel,

* *The Wheat Plant*, by W. Carruthers. (Johnston, 3d.)

iron, copper, of about the same length and weight as the Wheat-stalk. The latter is a fine example of strength combined with lightness and economy of material. The "nodes"—more strictly, the swollen bases of the leaf-sheaths—are of great importance. The actual node forms a solid partition across the otherwise hollow stem and thus gives it greater rigidity; the swollen base of the leaf-sheath, just above the "node" itself, remains capable of growth, and, in the lower parts of the plant especially, if the stem is laid horizontally (*e.g.* by wind), the lower side of the "node" grows rapidly and thus brings the shoot into the vertical position again; the lower "nodes" also give out roots.

Examine young ears and study the stages in the ripening of the fruit; the stigmas and stamens fall off after fertilisation, and the ovary grows into the grain.

289. Oat (*Avena sativa*) is probably derived by cultivation from the Wild Oat-grass (*A. fatua*). It can be cultivated above the limits of height and of latitude at which the cultivation of Wheat stops. In this country Wheat ceases to be a regular crop if the rainfall exceeds about 33 inches a year, and if the average July temperature is below about 13° C. On upland farms the chief cereal crop is Oat, which is cultivated in Europe to latitude 69° N.

The ears of Oat are not arranged in a close spike as in Wheat, but in a loosely branching system, in which the main axis gives off branches, which may again branch, each branch ending in an ear, which hangs downwards. This branched inflorescence is called a **panicle**. Examine an ear and compare its structure with that of Wheat. Note the two large boat-like outer glumes, enclosing (usually) three pairs of smaller scales (each pair = a flowering-glume and a palea, as in Wheat), but usually only the two lower pairs contain a flower, the small uppermost pair enclosing merely the barren end of the axis of the ear. Each flowering-glume bears on its outer side, just below the tip, a long bristle called the **awn**, which is sharply bent at its middle. The flower itself resembles that of Wheat, consisting of two lodicules, three stamens, and an ovary with two feathery stigmas (Fig. 101).

Oat differs from Wheat in having a short toothed ligule to the leaf; a smoother and less hairy leaf-sheath; in having

awned flowering-glumes;* and in having the flowering-glume and the palea joined to the ripe grain, forming the "husk" which has to be removed by grinding—in addition to the differences already noted in the inflorescence.

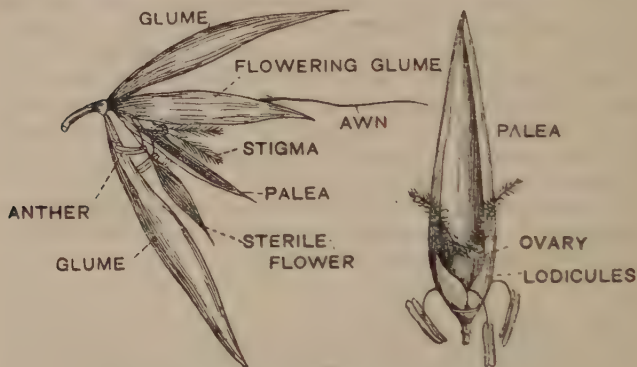


Fig. 101.—Spikelet and Flower of the Oat.
(In the second figure the flowering glume has been removed.)

290. The Grass Family (Graminaceae) is excelled in number of species by the Orchid, Bean, and Composite families; the known species in these four families number 4,000, 5,000, 7,000, and 11,000 respectively. Its success in the struggle for existence, however, is shown by the fact that Grasses vastly exceed all other families as regards the number of individuals, and in their wide distribution over the earth (see Art. 338).

Grasses are mostly herbaceous plants, though a few tropical types are woody and tree-like (*e.g.* Bamboos), but even the latter show no secondary thickening of the stem. They are easily distinguished from other grass-like plants—*e.g.* Sedges and some Rushes—by their two-rowed leaves and circular or flat (in cross-section) stems; the leaves very rarely (Bamboos) have stalks, and the stems are rarely solid (Maize, etc.) and rarely branch in the upper parts. Most Grasses are perennial, though several (besides Wheat and Oat) are annual—*e.g.*

* Some varieties of Wheat ("bearded" varieties) have an awn, especially in dry climates.

Sea and Wall Barley, Darnel, *Poa annua*. Annuals are easily recognised as such by all the shoots bearing inflorescences, but some Grasses (e.g. Barleys and Bromes) may be either biennial or perennial, according to conditions of habitat. Perennial Grasses grow by means of buds which arise from the lowest nodes of the shoot, within the leaf-sheaths.

The general habit of the plant depends largely on the way in which these buds grow out. (1) The new shoots grow up inside the leaf-sheaths and the plant then forms only tufts or tussocks—e.g. Sheep's Fescue, Cock's-foot, Timothy, Dog's-tail; (2) the shoots grow up in the sheaths, but some or all of them later grow along the soil as runners; (3) the buds break through the leaf-sheaths and either form runners (*above ground*) or creeping *underground* stems ("stolons"). Some Grasses vary in habit; for instance, the common Bent-grass (*Agrostis alba*) is tufted when growing on dry heaths, but has runners or stolons when in rich moist soil, while there are several varieties of Sheep's Fescue with stolons. Other examples of tufted (tussock-forming) Grasses are Hair-grass (*Aira*), Mat-grass (*Nardus*), Bromes, Rye-grasses. Yorkshire Fog and Marsh Foxtail are examples of Grasses with runners. Common and easily-recognised stolon-forming Grasses are Couch-grass, Lyme-grass, and Marram or Sea Mat-grass (*Psamma*).

In most Grasses the leaf-sheath is split down the side opposite the blade and rolled round the stem so that one edge overlaps the other, but in a few cases the sheath is entire—e.g. the Water-grass (*Glyceria*), Cock's-foot, Bromes. In Yorkshire Fog and False Oat the prominent keel of the blade runs down as a ridge on the sheath; in some Fescues, Rye-grasses, and Yorkshire Fog the sheath is red. Most Grasses have a membranous ligule, as in Wheat and Oat, but sometimes it is represented only by hairs—e.g. Purple Bent (*Molinia*), or may be very small or absent—e.g. most Fescues. The leaf-blade is flat, thin, and soft in most Grasses; it has large air-chambers in the floating Water-grass (*Glyceria*); it is dry and harsh, with a spiny tip in Wall Barley; firm, hard, and leathery in coast-grasses (*Elymus*, *Psamma*) and moor-grasses (*Nardus*, Fescues, Hair-grasses in which the leaf is narrow, bristle-like, and permanently rolled up).

The margin is even in most Grasses, but rough with minute teeth in Millet-grass, Oat-grass, Timothy, Quake-grass, etc. The upper surface usually has ridges, one over each vein; the ridges sometimes bear small teeth, giving the leaf a rough feel. The surface is, however, usually smooth, though in several Grasses it is hairy, the hairs often being found chiefly on the ridges; some common hairy-leaved Grasses are Yorkshire Fog, Bromes (*Bromus mollis* and *B. asper*), Oat-grasses, and Sweet Vernal Grass.

The rolling and folding of many Grass leaves are due to the presence of special epidermis-cells ("motor-cells") on the upper side of the leaf. These cells on losing water (when the air is dry and the transpiration current is flagging) contract and draw together the adjacent parts of the leaf. In the simplest cases there are two rows of motor-cells, one on either side of the midrib (e.g. *Poa*), or a single band extending over the midrib (e.g. Cock's-foot), so that the leaf is merely folded

(becoming V-shaped in cross-section) by their contraction. In most cases, however, there is a row of these cells at the bottom of each groove, between the ridges, so that the leaf can be rolled up to form a tube when the air is dry or hot; this rolling-up is easily observed in Meadow Fescue or in Tufted Hair-grass, the leaf rolling up when allowed to dry, and unrolling again when set in water. The common coast-grasses *Elymus* and *Psamma* also show the rolling and unrolling very plainly. In Sheep's Fescue, Wavy Hair-grass, *Nardus*, and some other moor-grasses, the motor-cells are not well developed and the leaf is permanently rolled up.

The flowers of Grasses are arranged in spikelets. We have already examined the spikelets or "ears" of Wheat and Oat, with which other grass-spikelets agree in general structure, each spikelet consisting of an axis bearing two opposite rows of scales which vary in size, shape, and texture, and some of which enclose flowers. Since the composition of the spikelet and the form of the inflorescence afford a good method for distinguishing the Grasses, we shall note some of the chief points here, for comparison with Wheat and Oat, and then give the characters of the commoner British Grasses.

In some cases the spikelet contains a single flower (*Psamma*, *Nardus*, *Milium*, *Alopecurus*, *Phleum*, Barley, *Agrostis*), or a single perfect flower with one or more male flowers (Sweet Vernal Grass, *Holcus*, False Oat). In *Nardus* and *Lolium* the spikelet has only one outer glume instead of two, while in Sweet Vernal Grass there are four. The outer glumes are rarely awned (*Nardus*, *Phleum*, Couch-grass); in Barley they are narrow, pointed, and stiff, but in most Grasses they are boat-like. The flowering-glume and the palea are often awned, especially the former (Oat-grass, False Oat, Barley, Bromes, Darnel, etc.); the palea is usually smaller and more delicate than the flowering-glume, and it usually has two side-veins but no midrib.

The awn carried by the flowering-glume (or by the empty glumes, or by all the glumes) grows from the midrib and may be terminal or inserted on the back of the glume. Awns act as a protection against birds and browsing animals; in some cases they aid in dispersal by wind or by animals. Besides these uses the awn has a vein, green tissue, and stomates, so that it can assimilate and transpire, and it doubtless helps in the nutrition of the developing grain. The awn probably corresponds to the reduced leaf-blade, the basal part of the glume to the leaf-sheath, and the free portion beyond the awn to the ligule of a leaf. The two lodicules (absent in Sweet Vernal Grass, *Nardus*, Foxtail, etc.) of most Grasses (three or even more occur in some foreign Grasses, e.g. Bamboo) are probably mere extra scales, not representing a perianth.

In all British Grasses there are three stamens (except Sweet Vernal Grass, which has two), and the pistil has two feathery styles, right and left (except *Nardus*, which has a single style). In some foreign Grasses there is only one stamen, in others six, while some have as many as forty; while there may be three styles (some Bamboos) or a single long style (e.g. Maize). Hence the typical Grass flower consists simply of two stigmas and a single carpel, with no perianth. The "styles" do not correspond to two carpels in this family. The lodi-

cules, when present, are said to swell up and push apart the scales enclosing the flower, so that the stamens and styles may more easily project from between them.

In most Grasses the pollen is shed before the stigmas are ready to receive pollen, but in some Grasses—*e.g.* Sweet Vernal Grass, Foxtail—the opposite is the case, *i.e.* the flower is protogynous. In some foreign Grasses the flowers are unisexual—*e.g.* Maize, where the feather-like male inflorescences occupy the top of the plant, while the female ones (“cobs”) are near the base; in some cases the male and female flowers are on separate plants. In some British Grasses (Yorkshire Fog, False Oat, etc.) one flower in each spikelet has stamens only.

In most cases there is a chance of cross-pollination, but most cereals are largely self-pollinated; in Rye the flowering-glume and palea do not separate at all, hence the flowers are self-pollinated. Grasses are wind-pollinated (what are their adaptations for wind-pollination?), but some, *e.g.* Sweet Vernal Grass, have been seen to be visited by flies.

In most British Grasses the grain remains within the flowering-glume and palea, as in Oat, and becomes detached along with these and the part of the axis of the spikelet which bears them. There are several adaptations for dispersal of the grains by wind or by animals. In Hair-grass (*Aira*) there are silky hairs below the flowering-glume, and in many cases the glumes expand and act as wings; some Grasses have small light grains, easily carried by the wind. The awns, especially when bent, catch on to animals; a familiar example is seen in Barley, the awn of which twists and untwists when one breathes on it, and causes the grain to creep up one's sleeve. The awns of some foreign Grasses have arrangements for becoming attached to animals, for burying the grain in the soil, and in some cases for wind-dispersal as well (*e.g.* *Stipa*).

†**291. Classification of British Grasses.**—The common British Grasses may be roughly divided into two groups, for purposes of identification: (1) those in which the spikelets are arranged in a spike, as in Wheat; (2) those with spikelets in a raceme or panicle, forming distinctly stalked tufts or groups on the main axis, as in Oat.

I. Inflorescence a spike.

A. Spikelet with only 1 perfect flower.

1. Inflorescence a spike of simple spikelets *Nardus*.
2. Inflorescence with spikelets in sessile tufts of 3 or more.

(a) Spikelets awned, in 3's (1 or 2 barren) at each notch on main axis *Hordeum*.

(b) Spikelets awned but crowded all round main axis.

- (i) Awn hair-like, on back of flowering-glume (no palea) *Alopecurus*.
- (ii) Awn = pointed tip of flowering-glume ; palea present.
 - (a) Plant with stolons *Psamma*.
 - (b) Erect plants *Phleum*.

B. Spikelet with at least 2 perfect flowers.

1. Spikelets in 2 rows on stout notched axis.

- (a) Spikelets fixed edgways on axis *Lolium*.
- (b) Spikelets fixed sideways on axis.
 - (i) Spikelet flat, outer glumes equal *Agropyrum*.
 - (ii) Spikelet long, outer glumes unequal *Brachypodium*.

2. Spikelets in groups of 2 or more on axis.

- (a) Spike long, fertile spikelets with 3 to 5 flowers.
 - (i) A pasture grass *Cynosurus*.
 - (ii) A sand-binding coast-grass *Elymus*.
- (b) Spike short, egg-like *Sesleria*.

II. Inflorescence a panicle with spreading or tufted stalked spikelets.

A. Spikelet with only 1 flower.

- 1. Inflorescence rather compact, stamens 2. *Anthoxanthum*.
- 2. Inflorescence loose and spreading.
 - (a) Tall reed-like plants in water or marshes *Diarrhiza*.
 - (b) Slender land-plants.
 - (i) Tall shade-grass in woods, spikelets few *Milium*.
 - (ii) In open places, spikelets numerous *Agrostis*.

B. Spikelet with more than 1 flower.

1. Only 1 perfect flower, the other usually male.

- (a) Shade-grass in woods, awnless *Melica*.
- (b) In open places, awns present.
 - (i) Upper flower perfect, lower male ; flowering-glume of lower flower has bent, twisted awn *Arrhenatherum*.
 - (ii) Upper flower male, lower perfect ; hairy plants with lower leaf-sheaths red *Holcus*.

2. Spikelet with at least 2 perfect flowers.

- (a) Panicle short, tufted, with stiff stalks and harsh spikelets *Dactylis*.
- (b) Panicle with all the spikelets on stalks longer than themselves.

(i) Panicle close, spikelets erect and keeping near main axis.

(a) Spikelets awnless, purple, with 2 or 3 flowers; moor-grass. . . *Molinia*.

(β) Spikelets with 6 or more flowers; water-grass. . . *Glyceria fluitans*.

(ii) Panicle loose, branches spreading or drooping.

(a) Spikelets awnless.

*Spikelets few, large, flattened, hanging on long stalks . *Briza*.

**Spikelets numerous, small, long, pointed, not drooping . *Poa*.

(β) Spikelets awned.

*Awn terminal or nearly so.

†Awn long, between teeth of forked flowering-glume . *Bromus*.

††Awn short or absent *Festuca*.

**Awn inserted on middle of back of forked flowering-glume.

†Awn long and stiff, projecting from spikelet (3 to 5 flowers) . . . *Avena*.

††Awn hair-like, hardly projecting, spikelet with 2 flowers . . . *Aira*.

†292. **Notes on Common British Grasses.**—Mat-grass (*Nardus stricta*), a wiry tufted moor-grass with bristle-like rolled-up leaves; spikelets all turned to one side of spike; spikelet has no outer glumes, consisting merely of flowering-glume, palea, three stamens, and ovary with one stigma-plume.

Barley (*Hordeum*) with cleistogamic flowers: *H. murinum*, Barley-grass or Wall Barley, common everywhere, is annual, the other species perennial; in *H. sylvaticum*, in woods, the central spikelet is male, and the two side ones perfect, but in other species the central spikelet is perfect and the side ones rudimentary; *H. pratense* and *H. maritimum* are common, the latter being a coast-plant.

Foxtail (*Alopecurus*): *A. agrestis*, annual weed, has outer glumes joined to middle; *A. pratensis*, in pastures, has underground stems, branches of "spike" each with 3-6 spikelets; *A. geniculata*, in wet places, has creeping stems with rooting nodes, spike-branches each with 1 spikelet.

Marram (*Psamma arundinacea*), a sand-binding coast-plant with stolons, stems 2-4 ft. high, leaves rolling up when dry, "spike" 3-6 ins. long.

Cat's-tail (*Phleum*), like Fox-tail, but palea and lodicules present; *P. pratense*, Timothy-grass, has stems 6-18 ins., tufted, "spike" 1-6 ins.; *P. arenarium*, coast-plant, annual, has stems 2-6 ins., spike 1 in.

Agropyrum, allied to Wheat: *A. repens*, Couch-grass, a troublesome weed with stolons; *A. caninum*, not so common, has no stolons; flr.-glume has a long awn, outer glumes short awns; *A. junceum*, sand-binding coast-plant, spike only 2-4 ins. long, otherwise like *A. repens*, but with stiffer leaves.

Rye Grass (*Lolium*), like *Agropyrum*, but each spikelet has only one outer glume, very long, except top spikelet, which has 2 glumes; *L. perenne* is much commoner than *L. temulentum*, Darnel-grass; the latter is annual, taller, and with larger "spikes."

Wood False-Brome (*Brachypodium sylvaticum*), a shade-grass, stem 1-3 ft. ; leaf $\frac{1}{2}$ in. broad, bright-green ; spike 2-6 ins. with 8-18 spikelets, each with numerous flowers.

Dog's tail (*Cynosurus cristatus*), a pasture grass, spike 1-2 ins., spikelets in clusters, and only the end-spikelet of each cluster bearing flowers.

Lyme-grass (*Elymus arenarius*), a coast-plant with stolons ; stems 3-6 ft. high, "spike" 6-12 ins. (note differences between *Elymus* and *Poa*).

Sesleria, in hill-pastures, chiefly in limestone districts (not in South of England), tufted, 6-12 ins. high, leaves narrow and stiff ; spike about $\frac{1}{2}$ in. long, spikelets in pairs, bluish.

Reed-grass (*Digraphis arundinacea*), a tall plant, in marshes, with creeping stolons, erect stems about 4 ft. high, leaves $\frac{1}{2}$ in. broad ; panicle 4-8 ins. long, lower branches spreading slightly ; *Phragmites communis*, the Great Reed-grass, has similar habit, but stem longer, leaf broader ; panicle 10-18 ins., much-branched, rather drooping, silvery owing to hairs on flowering-glumes.

Sweet Vernal Grass (*Anthoxanthum odoratum*), flowers protogynous, in spike-like panicle about 3 ins. long ; a slender smooth perennial, 1-2 ft. high, leaves hairy.

Millet-grass (*Milium effusum*), in damp woods, pale green, stems often 4 ft. high ; panicle 5-10 ins., very loose, branches in spaced-out whorls.

Bent-grass (*Agrostis*), like *Milium* in form of panicle, but flowering-glume is short and does not become hard over the fruit ; the common species *A. alba* has short flat leaves and no awns, but *A. canina* and *A. setacea*, heath-grasses, have longer and narrower and have awns on fl.-glumes.

Melick-grass (*Melica nutans*), in woods, with about 12 drooping 2-flowered spikelets on one-sided panicle ; *M. uniflora* has longer and narrower leaves and erect spikelets.

False Oat (*Arrhenatherum*), in meadows and hedgerows, stolon often with tuberos swellings, stems 2-3 ft. high, not tufted, leaves few, panicle 6-12 ins. long.

Holcus: *H. lanatus*, Yorkshire Fog, hairy all over ; *H. mollis*, not so common, hairy chiefly at nodes.

Cock's-foot (*Dactylis*), a well-known Grass, with lower branches of panicle standing out stiffly ; spikelets flat, harsh.

Purple Bent (*Molinia*), on wet heaths, stem 1-4 ft. ; tufted ; leaves rigid, narrow above ; panicle 6-12 ins., often purple.

Water Sweet grass (*Glyceria fluitans*), in streams, with creeping stems and floating leaves ; panicle erect and slender, 1-2 ft. long ; *G. aquatica*, less common, grows in wet places, panicle shorter, but spikelets more numerous and smaller.

Quaking-grass (*Briza media*), common in meadows, 1-2 ft. high ; panicle 2-4 ins. long, with large rounded or egg-like spikelets hanging from the long slender branches.

Meadow Grass (*Poa*) : the commonest is *P. annua*, which is tufted, about 6 ins. high, with flat bright-green leaves, panicle loose about 2 ins. long, and flowers nearly all the year, often germinating, flowering,

setting seeds, and dying away in a few weeks; *P. pratense* has stolons, stems 1-2 ft., panicle more spreading; *P. trivialis* has no stolons, panicle longer; *P. nemoralis*, in woods, is more slender and has narrower leaves.

Brome-grasses (*Bromus*): *B. sterilis*, leaves downy; panicle 6-12 ins. long, very loose; nodding spikelets, about 2 ins. long with awns, on long branches, awn longer than glume itself; *B. asper* is larger than *B. sterilis*, spikelet about 1 in. long, awn shorter than glume; the ubiquitous and variable *B. mollis*, often divided into several species, but panicle never so large or loose as in *B. sterilis* or *B. asper*, and the flowering-glume short and egg-like, not narrow.

Fescue-grasses (*Festuca*), differing chiefly from *Poa* in the longer, more pointed, or awned glumes, from *Bromus* in having a more compact panicle and the awns more terminal; the commonest species are Meadow Fescue, *F. elatior*, and Sheep's Fescue, *F. ovina*—both often split into several species; *F. ovina* and its varieties have bristle-like rolled-up leaves, and grow chiefly in hill-pastures.

Wild Oat (*Avena fatua*), annual, 2-3 ft. high; panicle 6-10 ins. long, spreading; spikelets green, drooping, nearly 1 in. long; *A. pratensis* is perennial, 1-2 ft. high, panicle narrower and less branched; spikelets erect, about $\frac{1}{2}$ in. long.

Hair-grass (*Aira*, allied to Oat, but spikelets much smaller): *A. precox* and *A. caryophyllea* are small annuals, seldom over 6 ins. high; the former has small dense narrow panicle, the latter has loose panicle, as have also the large perennial species *A. caespitosa*, 2-4 ft. high with stiff flat leaves, and *A. flexuosa*, 1-1 $\frac{1}{2}$ ft. high with narrow rolled-up leaves.

QUESTIONS ON CHAPTER XVI.

1. Describe the structure of a Wheat grain, as seen with a lens. Give sketches.

2. Describe the growth of a Wheat seedling up to the time when four or five foliage-leaves are visible. What structure can usually be found at this stage, on opening up the shoot?

3. Describe the shoot- and root-systems of a growing Wheat plant, about the end of May, omitting the flowers. What is meant by "tillers"? Give sketches.

4. Describe carefully the structure of a "node" of the Wheat plant. How do the nodes differ from the rest of the shoot, and what is the importance of this difference?

5. Describe the spike of Wheat, and give a careful account, with sketches, of the structure of a single "ear" ("spikelet").

6. Describe a few of the weeds found growing in a cornfield (1) when the Wheat is young, (2) when it has reached its full height. How are these weeds adapted to their mode of life?

7. Where does the food come from which goes into the ripening grains of Wheat?

8. What enables the slender Wheat stem to bear the heavy fruiting spike?

9. Describe the structure of an Oat plant (shoot, inflorescence, and flowers), and draw up a tabular comparison between Wheat and Oat.

10. What wild Grasses are most closely allied to Wheat and to Oat respectively? Where do these Grasses grow?

11. Describe the general characters of the Grasses found growing (1) in shaded woods, (2) in meadows, (3) in water or in marshes, (4) at the seaside. Give several examples of each and note their adaptations to their habitat.

12. Mention and describe several Grasses found growing on heaths and moors. In what respects do they differ from meadow-grasses?

13. Describe the structure of the flower and the mode of pollination of any common wild Grass you have examined. Give sketches.

CHAPTER XVII.

POPLARS AND WILLOWS.

293. Poplars (*Populus*) and **Willows** (*Salix*) are closely allied, forming a family (Salicaceae) which is sharply marked off from all other catkin-bearing plants. A catkin is simply an inflorescence consisting of a main stem or axis which bears either male flowers or female flowers, each flower arising in the axil of a leaf (bract) and having a very simple structure. The male and female catkins are on separate plants.

294. The best known Poplar is the **Black Poplar**, which we shall take as a type for first study. The main part of the root system grows deep into the soil, but some of the roots run along, more or less horizontally, a little below the surface. The shallow roots often send up leafy shoots ("suckers"). The tree is rarely over a hundred feet high; most of the branches bend upwards, and the tree has a loose appearance and a "lopsided" crown.

The leaves (Fig. 102) have long stalks and the upper part of the stalk flattened at right angles to the blade, so that the leaf hangs loosely and quivers in the gentlest wind. It has been suggested that two advantages arise from the tremulous character of the leaves in this and several (not all) other



Fig. 102.—The Poplar : Twig and Male Catkin.

Poplars :—(1) the resistance offered to the wind is lessened, so that the thin twigs can better withstand the strain ; (2) the evaporation of water from the leaf is increased, an advantage in rapidly-growing trees with a good water-supply from below. The first suggestion is supported by the fact that in Poplars with *thick* twigs, *e.g.* Lombardy Poplar, the leaf-stalks are not flattened; the second by the fact that Poplars “prefer,” *i.e.* thrive best in, deep moist soils.

The leaves vary in shape, but the margin of the blade is always regularly toothed, its upper and lower sides are almost the same in colour, and it has no hairs—these points distinguish our type from other Poplars. The tree sheds not merely

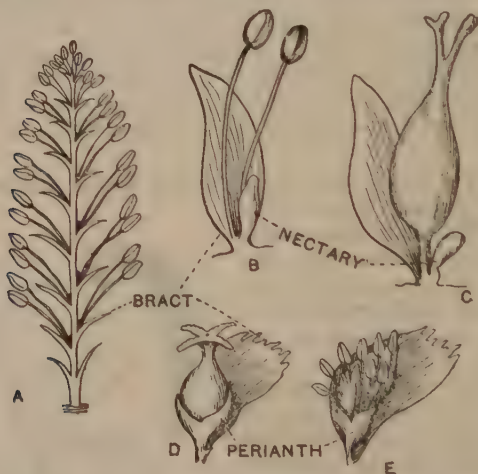


Fig. 103.—Salicaceae.

A, Male Catkin ; B, Male Flower ; C, Female Flower of Willow ;
D, Female Flower ; E, Male Flower of Poplar.

its leaves but whole twigs, sometimes as long as six feet ; an absciss-layer (Art. 155) is formed just as in the case of a leaf, so that a clean cork-covered scar is left when the twig is cast off.

The buds are long, pointed, smooth ; each has four scales—an outer concave scale on the side away from the stem and

three inner ones. In spring these scales fall off, together with the stipules of the sticky young foliage leaves. The side buds generally grow into dwarf shoots or into catkins, while the end bud grows into a long shoot. The highest bud is not really the end bud; as in many other trees, the real end bud does not develope at all, the highest axillary or side bud replacing it in growth.

The long hanging catkins (Figs. 102, 103) open before the leaves unfold. Each catkin is produced from a special bud, which resembles an ordinary bud in having four scales. The bracts are fringed at the free (outer) edge, but are not hairy. Each flower has a short stalk bearing a shallow lop-sided cup-like organ. In a male catkin we find within this cup a tuft of stamens (about forty), each with a red anther. At first the male catkin is erect or horizontal and the filaments are very short, but soon the catkin-axis lengthens, the catkin droops, the bracts fall off, and the filaments rapidly grow longer and push out the anthers. Then the anthers open and shed the pollen, which is carried by the wind, and soon the catkin falls off the tree—usually before all the anthers have opened. In the female catkin the cup surrounds the base of the pistil; above the ovary (one-chambered, with numerous ovules in two lines on the wall) are two large yellow branched stigmas. After pollination the axis of the catkin lengthens and the ovary grows into the fruit (capsule), which splits down along two lines halfway between the two lines of seeds, then the two valves roll outwards and the seeds escape. Each seed has a tuft of hairs arising from its stalk and serving for wind-dispersal.

For a comparison of the flowers of Poplars and Willows see Art. 222.

295. The Lombardy Poplar is simply a “pyramidal” variety of the Black Poplar, distinguished by its deeply furrowed bark and especially by the strong tendency shown by the branches to bend upwards and grow erect. Connected with this peculiar habit, which enables one to recognise the tree from a great distance, is the fact that only the buds on the *outer* side of the tree, i.e. those which are most exposed to light, grow out to form shoots.

296. The Aspen, the smallest of the common Poplars, is rarely over fifty feet high, with a slender trunk (about 1 ft. diameter). The bark remains smooth and light-coloured for many years; the leaves are

rounded and not pointed. The buds and flowers resemble those of Black Poplar, but the flowering buds are more distinct from the ordinary buds, being larger and less pointed; the bracts bear numerous long hairs on their edges; the stamens are fewer (about ten); the stigmas are red, not yellow.

297. The **White Poplar** resembles the Aspen in many respects, but is easily distinguished by (1) the white down on its leaves (lower side) and young twigs, (2) the dry and hairy buds, (3) the frequently lobed leaves, (4) the less marked flattening of the leaf-stalk, (5) the slight hairiness of the bracts, (6) the four slender yellow stigmas. It grows very quickly and may become a hundred feet high in forty years, with a massive trunk. The White Poplar, like the Black, has a "pyramidal" variety.

298. There are many different **Willows**, including varieties and hybrids, in Britain, but the commoner kinds are fairly easy to identify, and there are many points on which most of our Willows agree pretty closely.



Fig. 104.—The Willow, with Male (lower) and Female (upper) Catkins.

The leaves are alternate, with stipules, and usually have prominent cushions which run down the stem for some distance. The buds, which are generally pressed against the stem, may either produce long shoots bearing leaves, or short shoots which end each in a catkin; the short shoot sometimes bears a few leaves below the catkin (*e.g.* Crack Willow). Each bud shows on the outside only one large rolled-up scale; sometimes there are two small buds inside this scale, one on each side of the ordinary bud.

The catkin-bracts (Figs. 103, 104) have silky hairs on the outer surface, and each flower has a green or yellow nectary, or two nectaries, at the base of the stamens or pistil on the side nearest the axis of the catkin. The male flower has few stamens (two to five), the number (though not constant) serving to distinguish some of the species; the anthers are

yellow, the filaments long. The female flower has a pear-shaped ovary, generally carried on a stalk; the tapering upper end runs into a style with two stigmas which are sometimes branched, and the ovary has the same structure as in Poplars. Bees visit the flowers for honey and pollen. The capsule opens by two valves, as in Poplars, and the seeds have a tuft of hairs.

Willows may be roughly divided according to the presence or absence of long slender quickly-growing shoots (osiers) which often grow about nine feet long in a single season, or according to the breadth or narrowness of the leaves. For other methods of classification see a "Flora."

299. Among narrow-leaved Osier Willows a typical example is the **Crack Willow** (*Salix fragilis*), the yellowish osier-twigs of which can easily be broken off at the base, leaving a clean scar. It is often seen in the "pollard" form (as are various other Willows as well as Poplars), owing to repeated cutting of the osier-twigs. The long (3 to 6 ins.) leaf tapers to an oblique tip, and has both sides smooth; at the top of the stalk, just below the blade, there are usually small glands (compare leaf of Cherry). The stipules, which soon fall off, are half heart-shaped. In spring the end bud grows into a long shoot, while of the side buds (more pointed, closely applied to stem) some grow into ordinary shoots and others into short shoots, which bear first a few small leaves and end in a catkin. There are two nectaries; two stamens; two stigmas, each slightly forked; capsule stalked.

Four other narrow-leaved Willows may be mentioned. Of these (3) and (4) differ from the Crack Willow in having no foliage-leaves on the flowering dwarf shoots. (1) **Almond-leaved or French Willow** (*S. triandra*) resembles Crack Willow in most respects, but the leaf-stalk has no glands, the bracts are nearly hairless, and the male flower has three stamens. (2) **White Willow** (*S. alba*) has leaves 2 to 4 ins. long, silky on both sides; stipules narrow and tapering; one nectary; two stamens; capsule-stalk very short. (3) **Common Osier** (*S. viminalis*) has very long leaves (4 to 10 ins.), silky below, with wavy edge and narrow stipules; one nectary; capsule hairy. (4) **Purple Osier** (*S. purpurea*) is a small shrub (5 to 10 ft.), with short-stalked leaves; stipules small or absent; catkin-scales dark purple above; two stamens with their filaments joined (sometimes right to the top, so that there seems to be a single stamen with a double anther), anthers purple.

300. Among the broad-leaved Willows the **Goat Willow** or **Common Sallow** (*S. caprea*) is a small tree, often about thirty feet high. It has no long osier-shoots; the spreading main branches bear knotted twigs, useless for basket-making. The leaves vary greatly in form, but are generally more or less oval and pointed, sometimes with a long bent or twisted tip; the leaf is wrinkled, the margin wavy, the upper side smooth but the lower side usually downy. The stipules are half kidney-shaped. The catkins open in March or April; the male catkin is short (about 1 in.) and stout, but the female lengthens to about three inches. The scales (bracts) are hairy, with black tips; the fruits open in May or June.

Allied to Goat Willow, and perhaps only varieties of it, are the **Round-eared Willow** (*S. aurita*) and the **Grey Sallow** (*S. cinerea*, sometimes called the Sallow). The former is a small shrub with straggling branches, short (up to 2 ins.) wrinkled leaves, kidney-shaped stipules, short catkins (about $\frac{1}{2}$ in.); the latter is a larger plant and has its twigs covered with a grey felt of short hairs.

The **Bay-leaved Willow** (*S. pentandra*) is a small tree with thick smooth shining fragrant leaves, fairly broad and pointed; the male flower has usually five stamens, but sometimes more. The **Creeping Willows** are small dwarfed plants, divided into several species. The commonest (*S. repens*) grows abundantly on commons and heaths and has small oblong leaves; of the others, *S. herbacea* (the smallest British shrub) grows on the higher hills in Britain, except in the south of England, *S. reticulata* only on Scottish hills, both having short creeping stems (sometimes underground) and small ($\frac{1}{4}$ to $\frac{1}{2}$ in.) rounded leaves.

QUESTIONS ON CHAPTER XVII.

1. How can you tell a Poplar from a Willow in winter?
2. Describe and explain the process of "pollarding" Poplars and Willows.
3. Which Willows are used for basket-making? Where do these Willows grow?
4. Describe and compare the flowers of Willow and Poplar, giving sketches of their structure. How are the flowers pollinated? Compare the pollination adaptations of Willows and Poplars.
5. Describe the winter buds of a Willow or Poplar, with sketches.
6. How can you distinguish from a distance (a) the Lombardy Poplar, (b) the Aspen?

CHAPTER XVIII.

ALDER, HAZEL, BIRCH, OAK, BEECH.

301. Alder (*Alnus glutinosa*) grows chiefly in moist places, beside streams and pools, in marshes and bogs, but will thrive in drier places which are sheltered or in which the air is moist enough. It is generally a small tree, but may reach a height of sixty feet; the trunk, however, rarely exceeds a foot in diameter.



Fig. 105.—Alder. The twig shown at the left bears male catkins, four young female catkins (above), four fruiting catkins (below), and five resting buds; the twig at the right (summer) has four fertilized catkins.

The Alder is rather like the Hazel (Art. 302) in general mode of growth, being often shrubby owing to the production of numerous stool-shoots, but the roots rarely produce suckers. On the older parts of the shoot the bark is black and scaly; on younger parts it is brown, with very distinct lenticels.

The leaves (Fig. 105) have stipules which soon fall off; the blade is broad and usually notched at the end, and except at the base its edge is doubly toothed, the teeth being short. The large egg-shaped brown resting buds are peculiar in that each is on a stalk. The young leaves are pleated (Fig. 36, *plicate*), and both they and the twigs are sticky at first. The buds are covered by two or three scales, which are rather difficult to separate and have a waxy coating.

The catkins open in February before the leaves appear. Both kinds of catkins can be seen in the previous autumn, and in winter they are very conspicuous on the bare twigs. Needless to say, the ordinary resting buds of Alder contain only foliage-leaves.

The male catkins are cylindrical and are nearer the end of the shoot than the shorter female ones. Each scale is thickened at the outer edge and bears, on its (true) upper surface, three flowers, each with a green four-lobed "calyx" and four stamens. In the female catkin, which usually turns upwards and does not droop like the open male catkin, each scale bears two flowers resembling those of Hazel in structure but having no "calyx." After fertilisation the ovary grows into a dry akene; the scales become stalked, hard, and woody, giving the old female catkin the appearance of a Pine cone. The cone ripens in autumn, but remains closed until the following spring, when the scales become separated and the akenes (which have a spongy coat) may be blown away by the wind or may fall into water and be carried by it.



Fig. 106.—Young Shoot of Hazel.

The leaves have an angular divergence of one-third.

302. Hazel (*Corylus avellana*) is a small tree, rarely over 15 ft. high. There is usually no main trunk, but several branches starting at the base of the tree. From the base of the shoot arise numerous erect quickly-growing branches ("stool-shoots"), and similar branches ("suckers") are often given off by the root; the stool-shoots and suckers differ from the ordinary branches in having the leaves arranged

in three rows instead of two (Fig. 106). The bark remains smooth for many years, and has narrow transverse lenticels; in the older parts it becomes rough and scaly.

The leaves are stalked and simple, the blade varies in form and amount of lobing, but has irregular pointed teeth on the edge, a pointed tip, a rough surface, and is usually larger on one side of the midrib than on the other, especially at the base. Are the leaves more lopsided on the two-rowed or on the three-rowed shoots? Is the larger half of the blade that nearest, or farthest from, the free end of the twig? Examine the lopsided leaves of Elm, Lime, Begonia, and try to find out the advantages of this kind of leaf to the plant.

The twigs of the current year are hairy and have a zigzag appearance, the leaves (and buds) coming off singly at each bend. The buds are egg-shaped but rather flat, and are covered with brown scales; within these come pairs of silky stipules without leaf-blades, then stipules with young blades between them (Fig. 107), each young leaf being folded along the midrib.

The uppermost bud on each twig grows out and forms a long shoot, but in summer the end of the shoot dries up, then

the place of the lost end bud is taken by the uppermost side bud. Most of the side buds, however, grow into dwarf shoots, which may either bear a few leaves or may produce a male or a female inflorescence. The "male bud" differs from the ordinary buds and the female buds in the fact that it grows at once, in the year it is formed, and produces first a few buds (which next year will become ordinary shoots or else female catkins) and then ends in from two to five male catkins. The cylindrical male catkins, therefore, are visible in late summer, and by February (sometimes after a few fine days in January or even December) they open.



Fig. 107.—Young Foliage and Bud-Scales of Hazel.

The drooping male catkin (Fig. 108) has numerous concave green scales, each bearing on its downward face (its true upper face) two small scales and a number of stamens (Fig. 109); each stamen has a short filament ending in a one-lobed anther (a half-anther). There are usually eight of these

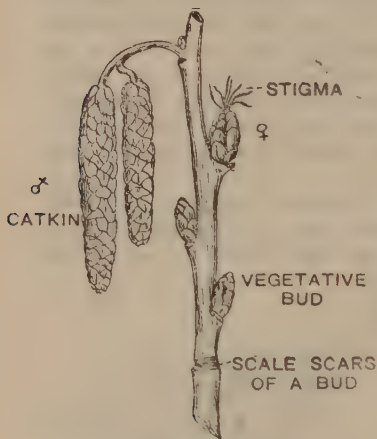


Fig. 108.—Male and Female Inflorescences of the Hazel.

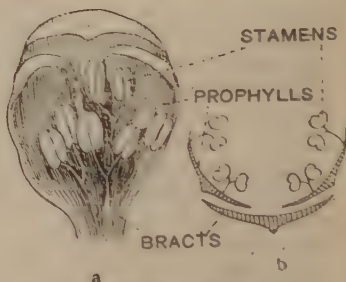


Fig. 109.—Hazel.
A, Male Flower; B, Diagram of same.

half-anthers, and (in some cases at least) their filaments are joined in pairs at the base, so that in reality there are only four stamens.



Fig. 110.—Two Female Flowers of Hazel in Axil of a Bract, each with two long Stigmas, and Diagram of same.

When the female bud opens, a tuft of about twenty scarlet stigmas projects from the top. Carefully dissect the bud and note the brown outer scales, then several pairs of stipules,

then a few small leaves, and finally about five bracts each with two female flowers (Fig. 110). The flower consists of an ovary surrounded by a double cup at the base and bearing on top two long red styles, but the lower parts are very small at the time pollination occurs. Only a few flowers in each catkin develop into nuts; the ovary has two chambers, each with an ovule, but the nut has only one seed. The cup

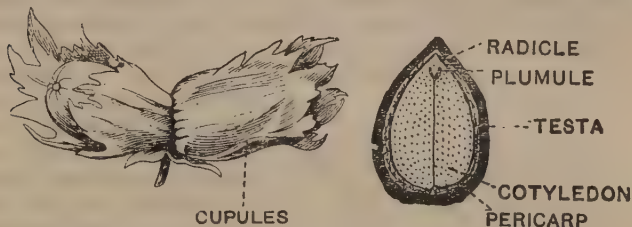


Fig. 111.—Two Hazel Nuts with their Capsules, and Section of Nut.

becomes leafy and very conspicuous as the nut ripens. What changes in colour, texture, taste, and size does the nut undergo while ripening? When are the nuts ripe? Note the embryo which fills the nut and has two large cotyledons containing starch and oil (Fig. 111). Sow ripe nuts, first soaking them in water; do the cotyledons remain below ground or come above it?

303. Birch (*Betula alba*) is easily recognised by its thin main stem (sometimes forty feet high), which runs up to the top of the tree and is rarely over a foot in diameter; its slender twigs, which often droop at the ends, and the light foliage, which together give the tree its graceful appearance; and its smooth thin white papery bark with long, dark transverse lenticels.

There are two varieties in Britain, "White" Birch and "Common" Birch; they are connected by variations and hybrids, but the "Common" Birch is distinguished by its branches being more spreading and rarely drooping at the ends, its twigs *not* being covered with hairs, its bark being, at the base of the trunk, rough, dark, and furrowed, and by its hairless and longer-tipped leaves with the blade placed

horizontally. The young bark is brown in both cases, becoming white later on.

The leaves are arranged all round the stem, but sometimes tend to form two rows; the stalk is thin, the blade variable in outline (heart-shaped, diamond-shaped, etc.), doubly toothed, with pointed tip. Since the leaves are relatively small, well spaced on the slender twigs, long-stalked, and hang vertically on the drooping twigs, they cast little shade. Hence the Birch catches but little light, as compared with trees which spread out their leaves and form a mosaic. It is, in fact, the most exacting tree in its demand for light, and



Fig. 112.—Birch. Twig showing male and female catkins.

conversely it grows worse in shaded places than any other tree in Britain. Between an extreme light-demanding tree like the Birch and an extreme shade-enduring tree like the Beech we get various intermediate trees. The buds are small, pointed, dark brown; some produce long shoots, others dwarf shoots. Each year the end of the long shoot dies and its growth is continued by the uppermost side bud.

The catkins open along with the leaves in March or April (Fig. 112). Both kinds are cylindrical; the female catkins are at first erect and more slender

than the male catkins, but later (in fruit) become much larger. The male catkins are visible during autumn and winter (as in Hazel) at the ends of twigs in twos or threes. In spring the male catkin lengthens and droops, the scales separate, and the pollen is blown out. Each scale (bract) bears (on its true upper surface) several small scales and three groups of stamens, each group consisting of two stamens each split into half-stamens (Fig. 113 c).

Each female catkin is produced inside a resting bud; in spring this bud grows out, produces a few foliage leaves, and ends in a slender catkin (Fig. 112). Each scale bears on its upper side two small scales (*bracteoles*, Fig. 113 A) and three flowers. Each flower consists of a pistil (like that of Hazel in structure), without any cup. The akene is flat and produced at each side into a thin wing. In autumn the scales fall off and the light-winged fruits are dispersed by the wind. Examine twigs in autumn, noting the ripe female catkins of this year, and the male catkins and the buds for next year; rub, or pick to bits, a fruiting catkin and note the scales and the winged akenes (Fig. 113 B). The seedling has two small green cotyledons, carried up; the first foliage leaves are less toothed and more hairy than the later ones.

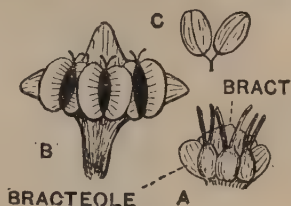


Fig. 113.—Birch.

A, Female flowers in axil of bract; B, Fruiting scale, with three samaras; C, stamen from male flower.

304. Oak (*Quercus robur*), the largest of British trees, sometimes 150 feet high, with massive trunk (up to 70 feet in girth, *e.g.* Cowthorpe Oak), is easily recognised at all times of year. Even when without its wavy-lobed leaves or its acorns, it differs from other trees in its gnarled and contorted main branches and in having its buds crowded round the ends of the twigs (see Art. 189).

In the commoner variety of the Common Oak (Stalked Oak) each group of acorns is carried on a stalk; in the other variety (Sessile Oak) the acorn group has no stalk. The Oak leaf has small stipules which soon fall off. In Stalked Oak there is no leaf-stalk, or a very short one, in Sessile Oak the leaf-stalk is long; in Sessile Oak the blade is firmer, more tapering at the base, and has hairs on its lower side.

The flowers appear with the leaves in April or May. The male catkin bears numerous flowers scattered singly or in groups on the axis; each flower (Fig. 114 c) has a deeply 5- to 7-lobed "calyx" and from 5 to 12 stamens. The

female catkin has fewer flowers (1 to 5); each flower has a shallow cup covered with triangular overlapping scales, and inside this, the future acorn-cup, there is a 6-toothed

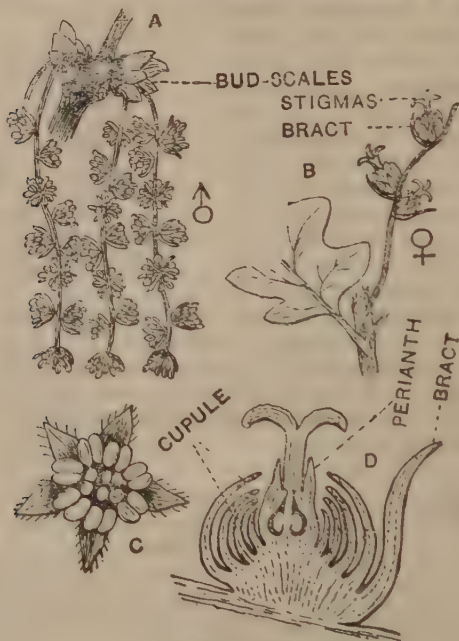


Fig. 114.—Oak.

A, Male; B, Female inflorescences; C, Male flower; D, Female flower in section.

“calyx” (Fig. 114 D, *perianth*) inserted above the small ovary, which has a style with three stigmas. The ovary has three chambers; the ovules (two in each chamber) are not even developed until after pollination. As a rule only one seed is present in the ripe acorn; still one often finds three or more, especially in looking for seedlings. The seed (Art. 92) is filled up by the embryo, whose thick cotyledons contain starch, together with tannin, oil, sugar, etc.

† A few notes may be added on some introduced Oaks commonly grown in Britain, which differ from the Common Oak in various details.

(1) Turkey Oak has the leaf-lobes long and pointed, and the acorn (not ripened until the year after the flowers open) has its cup covered with long outgrowths; this Oak is also called the Moss-cupped Oak. (2) Evergreen or Holm Oak, with evergreen leathery leaves, entire or with spiny margin, glossy above, greyish below. (3) Cork Oak, evergreen, with thick corky bark and wavy-lobed leaves.

305. Beech (*Fagus sylvatica*), which is so easily distinguished by its smooth grey bark, its ovate leaves, fringed with hairs when young, its long brown tapering buds, and its three-sided nuts in pairs within a four-lobed spiny cup, is one of our largest trees, often over a hundred feet high. It frequently has very characteristic rounded ridges or buttresses at the base of the trunk, which run out to the shallow roots.

The leaves (Fig. 115) are arranged in two rows, and on horizontal or inclined branches their insertion is nearer the lower than the upper side of the branches; by twisting of the stalks the blades all present their upper faces to the light. The blades vary in shape, but are usually symmetrical and taper above and below. On young trees the dead leaves often remain attached during the winter. Besides the ordinary long branches there are dwarf shoots which grow very slowly and bear few leaves each year; inspection of the "girdle-scars" (close-set scars of bud-scales of former end buds) will often show that a dwarf shoot has grown less in length in about twenty years than a long shoot in about a month. The dwarf shoots do not branch, and bear crowded leaf-scars and annual girdle-scars. Sometimes a dwarf shoot grows out, after several years, to form a long shoot, owing to the fall of a branch above it or some other cause which gives it plenty of light.



Fig. 115.—The Beech, with a Fruit.

Carefully examine a branch of Beech and note how beautifully the long and short shoots are arranged and mixed and how the sizes of the leaf-blades are varied, so that the leaves

form a close mosaic and catch a large amount of light. Hold the branch against the light, and you will understand one reason why the Beech casts such a dense shade and why so few plants can grow under Beeches; when growing in a wood the main trunk runs up nearly to the thick crown of the tree, but in the open the stem branches low down into several strong cylindrical trunks, while the leafy "crown" comes nearly to the ground. From these observations you will understand why Beech is called a "shade-enduring" tree (more so than any other tree in Britain), while Birch is called a "light-demanding" tree.

The long zigzag twigs have the buds standing off at an angle of about 60° ; the end-bud may either persist or be replaced by the uppermost side-bud. Each bud stands at the side (upper side) of the leaf-scar (small, oval, with three

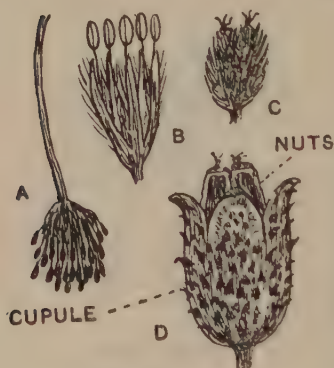


Fig. 116.—Beech.

A, Male inflorescence; B, Male flower; C, Female inflorescence; D, Cupule with nuts.

bundle-scars). In autumn the tips of the shoots cease to form leaves, but keep on forming stipules which act as bud-scales. The scales are pale brown, arranged in four rows; the outermost scales are broad, short, pointed, but those further in are longer, narrower, and more delicate in texture. The first seven or eight pairs of scales have no leaves, but the innermost pairs have a small leaf-blade between them, then come the pleated foliage-leaves with their stipules densely covered with silky hairs.

As a rule the highest buds on a twig grow into long shoots, those lower down into dwarf shoots, and the lowest ones remain dormant; the dormant buds do not, however, remain alive and capable of growth for nearly so many years in Beech (rarely 20 years) as in other trees, hence one does not see young shoots growing from the old trunks of Beeches, like those on Oaks, Elms, etc.

The flowers, which come out with the leaves in spring, are in clusters at the ends of slender branches which arise singly in the axils of the leaves, the female clusters being higher up on the twig than the male. The male branch has a long hanging stalk; that of the female branch is shorter, thicker, and erect. The numerous male flowers (Fig. 116 b) have each a bell-shaped "calyx" with five to seven teeth, covered with hairs, and about ten stamens. The female branch has only two flowers (Fig. 116 c) surrounded by a four-lobed cup covered with soft outgrowths; each flower has a "calyx" with four to eight teeth above the three-chambered ovary (two ovules in each chamber), and the style has three stigmas.

After fertilisation the cup becomes woody and its outgrowths stiff or even spiny; about October the four lobes spread out and let the nuts escape (Figs. 115, 116 d). The nut is filled by the embryo, which has two folded cotyledons. On germination the cotyledons are carried up and spread out as broad green leaves. For several years the young plant grows very slowly; each year the end of the stem bends over so that the leaves (set in two rows) shall not shade each other, then the upward growth for the next year is carried on by a bud on the top of the bend.

The "Copper" Beech is a variety of Common Beech in which the epidermis of the leaf contains a red pigment (dissolved in the sap of the epidermal cells); the mesophyll consists of green tissue, as in the ordinary Beech.

QUESTIONS ON CHAPTER XVIII.

1. How could you distinguish an Alder in winter? Where do Alders usually grow?
2. Describe, with sketches, the buds, young twigs, and leaves of Alder.
3. Describe the male and female catkins and flowers of Alder. Give sketches. At what time of year are the catkins formed? In what other catkin-bearing trees can both kinds of catkin be seen in winter?
4. Describe the fruit of Alder. In what respect do the fruiting catkins of Alder differ from those of other catkin-bearing trees? How could you distinguish an Alder "cone" from a Pine cone? Give sketches.

5. Describe the appearance of a Hazel in winter. How can you tell the Hazel (a) by its twigs and buds alone, (b) by its leaves alone, (c) by its fruits? Give sketches.

6. Describe the male and female catkins and flowers of Hazel. Give sketches.

7. Describe the appearance of a Birch in winter. How can you tell a Birch easily from a distance (a) in winter, (b) in summer?

8. Why is the Birch called a "light-loving" tree?

9. Describe the catkins and flowers of Birch. Which kind of catkin can be seen on the tree during the winter? Give sketches.

10. Describe the ripe fruiting catkin of Birch. How are the fruits dispersed? Give sketches.

11. How can you tell an Oak in winter by its twigs and buds? Give sketches. Why are the buds crowded at the tips of the twigs?

12. Describe the catkins and flowers of Oak. When do the catkins first appear? Compare Oak with Birch, Hazel, and Alder in this respect. Give sketches.

13. Describe the fruit of Oak and compare it with that of Hazel.

14. Describe the general appearance of a Beech (a) in winter, (b) in summer. What makes the Beech cast such a dense shade? Why is Beech called a "shade-enduring" tree?

15. Describe the inflorescences and flowers of Beech, with sketches. How do the inflorescences of Beech and Oak differ from those of Birch, Hazel, and Alder?

16. Describe the fruit of Beech, and compare it with that of Oak. How are Beech and Oak fruits dispersed?

CHAPTER XIX.

ELM, SYCAMORE, HORSE CHESTNUT, LILAC, ASH.

306. Elm (Figs. 117, 118).—There are two kinds of Elm in Britain, the **Common** or **English Elm** (*Ulmus campestris*) and the **Wych, Scots, or Mountain Elm** (*Ulmus Montana*); roughly speaking, most Elms growing south of the Trent belong to the former species, while most Elms north of the Trent belong to the latter.

In both Elms the bark is rough and shoots are often produced from the lower part of the trunk. Both grow into tall trees (up to about 120 feet), and have short-stalked simple entire doubly-toothed leaves arranged alternately in two side-rows on the stem. The blade is roughly heart-shaped in outline, but one half (that nearest the tip of the twig, or that farthest from it?) comes off the leaf-stalk lower down than the other half and bulges out, so that the blade is lopsided. The advantage of this lopsidedness is easy to observe if you hold a leaf-bearing twig up to the light and notice how the larger half of each blade tends to fill up what would be a space (if the leaf were symmetrical) between the leaf, the stem, and the leaf above. This peculiarity of the leaf-blade, enabling the leaves on a twig to catch more light without



Fig. 117.—The Elm, with Clusters of Fruits.

too much overlapping of each other, is a simple method of producing a leaf-mosaic; it is more pronounced in the Wych Elm (leaf 3 to 6 ins. long, up to 3 ins. across broadest part, taper-pointed) than in Common Elm (leaf about 2 ins. long, not so pointed).

In Wych Elm the crown is broader and the main branches more spreading than in Common Elm; the latter has its bark more deeply furrowed. There are two kinds of buds; the higher ones are pointed and grow into leafy shoots (either long shoots or dwarf shoots), while the globular lower buds produce clusters of flowers. The buds have much the same structure as in Hazel; the young leaves have stipules which soon fall off; the branches, like the leaves, are in two side-rows; the true end-bud dies off each year, and the uppermost side-bud replaces it.

The flower-buds open first, in March or April, each producing a dense tuft of small brownish-green flowers; each flower has a bell-shaped "calyx" with four to eight lobes, a stamen opposite each lobe, and a two-chambered ovary with two long red stigmas. At first the stigmas project beyond the stamens and are receptive, but after a time the filaments lengthen and carry out the anthers, which then open. The pollen is carried by the wind; it is obvious that self-pollination is prevented during the female stage of the flower, but it may occur when the anthers

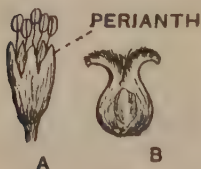


Fig. 118.—Elm.
A, Flower; B, Pistil.

of the flower open if cross-pollination has failed.

The ovary becomes an akene, with a thin wing around the seed-containing part; the fruits (oval, notched above) are at first green, but become brown and ripe by May. In Wych Elm the seed is at the centre of the fruit (about 1 in. long); in the smaller fruit of Common Elm (about $\frac{1}{2}$ in. long) it is above the centre. The seeds of Common Elm are said never to germinate in this country, but this is largely atoned for by the fact that this species of Elm sends up numerous suckers from its roots, so that one often sees a long stretch of hedge on each side of an old Elm, or a thicket of young Elms around the parent tree. The Common Elm is not

regarded as a native British tree, but as having been introduced within historic times. The Wych Elm, regarded as native, does not produce suckers, as a rule, unless the tree is cut down; its winged akenes (samaras) are well adapted for wind-dispersal, and in germination the green cotyledons are carried into the air.

Common Elm differs from Wych Elm chiefly in having smaller leaves, flowers, and samaras; fewer "calyx"-lobes and stamens; in the non-germination of its seeds in Britain, and its production of suckers in large numbers from the roots; in the direction of growth of its main branches and the shape of the crown.

307. Sycamore Maple or False Plane (*Acer pseudo-platanus*), usually called simply Sycamore (though this name was originally given to a wild Fig, *Ficus sycomorus*, growing in the East), is not a native of Britain, though so common here; its home is in central Europe and western Asia. The Sycamore is really a species of Maple; the only native British species of *Acer* is the **Field or Hedge Maple** (*A. campestre*), but two other species are commonly grown—**Norway Maple** (*A. platanoides*) and **Ash-leaved Maple** (*A. negundo*). They all have the leaves in crossed pairs (therefore in four rows, *decussate* arrangement) and a fruit which splits into two (sometimes three) winged akenes (samaras).

The **Sycamore Maple** (Fig. 119) is a fairly tall tree (up to 60 ft.); the bark long remains smooth, but eventually becomes rough and scaly. Each leaf has a stalk whose broad base extends about half round the stem; the blade (4 to 8 ins. broad) has five pointed toothed lobes and is shiny and dark-green above, dull and light-green below. The main veins spread out from the top of the stalk, one running to each lobe and giving off side-veins; in the young leaf the veins are fringed below with hairs, but in the old leaf the hairs are



Fig. 119.—The Sycamore, with Flowers.

confined to tufts at the points where the secondary veins join the five main veins. On a horizontal branch the leaves are arranged so that the blades may get as much light as possible; the leaf stalks vary in length, and those of the upper and lower rows of leaves become twisted, while the blades vary in size, in amount of lobing and sizes of the lobes, so as to produce an effective leaf-mosaic. On a more or less horizontal branch, the buds (Art. 187) on the upper and lower sides either remain dormant or grow into very short shoots, so that on an old branch of this kind the long twigs are confined to the flanks; but on more erect branches there are strong twigs on all sides, especially on the side farthest from the middle of the tree. How may these facts be explained?

A flowering shoot (how can you tell in winter which buds contain an inflorescence?) bears one or two pairs of leaves and ends in a long hanging bunch of stalked green flowers. At the base of the inflorescence branches bearing each about three flowers arise from the axis, but higher up it gives off single flowers. Note the five sepals, the five petals (narrower than the sepals), the stamens (8 to 12) inserted on a yellow ring-like cushion (nectary), the hairy flattened ovary (two chambers each with two ovules), and the short style with two curved stigmas. As a rule the central flower in each group has a fully developed pistil, and eight stamens with short filaments, but the anthers (though containing pollen) do not open, so that the flower is practically female. The other flowers are male, having eight to twelve stamens with long filaments, and a small sterile pistil. Sometimes a whole inflorescence consists of these male flowers; in all cases the male flowers appear to mature before the female flowers. The flowers are visited by insects, chiefly bees and flies.

The fruit has two spreading and diverging wings, one produced from the outside of each chamber or half-fruit. Each chamber contains a large rounded seed (Art. 93). Eventually the whole inflorescence falls off, leaving a saddle-like scar on the stem.

†308. The **Field Maple** is a small tree (rarely over 30 ft. high) with spreading branches; the bark has numerous fine furrows dividing it into scales. The leaves are smaller than those of Sycamore, with blunt lobes and both surfaces nearly alike. The buds are small and

pressed against the stem. The inflorescence is erect, and its branches are arranged so as to bring the flowers nearly to the same level; the flowers are male, female, or perfect. The wings of the fruits are horizontal or even bent downwards, and the seed-chamber is flattened.

The **Norway Maple** is rather like the Sycamore in size and general appearance, but the leaves are smoother and the buds are red (sometimes they are red in Sycamore); the inflorescence is like that of the Field Maple but with more flowers, and the fruit has horizontal wings but is larger than in Field Maple.

The **Ash-leaved Maple** or "Box Elder" is a North American tree with compound leaves; there are from three to five leaflets, the lower ones in pairs, the odd leaflet often three-lobed. The twigs droop, and are green when young; the bud has no proper scales, but is protected by the base of the leaf-stalk in whose axil it stands. The flowers have no petals and no nectary; they are completely unisexual, the male and female flowers being on different trees. The male flowers are in hanging tufts, each flower on a long stalk; the calyx is bell-shaped, the stamens (3 to 5) have long filaments. The female flowers are in loosely branched racemes; the sepals are small, and the pistil, with its long stigmas, projects well beyond them. The flowers open, with the leaves, in April, and are wind-pollinated; the brown fruits (ripe in August) have the two wings nearly parallel or converging at the top. The leaves are often variegated with white blotches, or may be entirely white in some cases, but the tree always has plenty of green leaves besides the variegated ones.

309. Horse Chestnut (*Aesculus hippocastanum*) is a large tree (about 60 ft.), with erect trunk and pyramidal head; it is a native of Asia and North America and was introduced into Britain about 1630. The name is probably derived from the resemblance of its seeds (too bitter for human food, though eaten by various animals) to the edible fruits of Sweet Chestnut, "horse" being a contemptuous prefix meaning coarse, as in Horse Radish, or as "dog" in Dog Violet, Dog Daisy, etc.

The twigs are thick, the buds (Art. 188) large, brown, and sticky; the branches ascend at first, then bend downwards and often curve up again at the ends. The bark is smooth for many years, but later becomes grooved and scaly. The leaves are in crossed pairs. As in Sycamore, the leaves differ according to their position on the branches, the lower ones having larger blades and larger stalks, but the mosaic is made more perfect by the fact that the leaves are compound, so that the individual leaflets can vary in shape and thus catch the light more fully. The leaf-stalk has a broad base and is also broadened at the top where the leaflets

(5 to 9, typically 7) come off. The leaflets themselves have no stalks; each has a sharp tip, just below which the leaflet is broadest, and a toothed edge. On a horizontal branch the lower buds either remain dormant or grow into small and short-lived twigs. When the inflorescence eventually falls off from the end of a flowering twig, a saddle-shaped scar is left, and the onward growth is usually continued by one of the uppermost side-buds.

The flowering branches (Fig. 120), whose buds are much larger than the ordinary buds, resemble those of Sycamore in general structure, but are erect; they open in April or May,



Fig. 120.—The Horse-Chestnut—Leaf, Flowers, and Fruit.

as a rule, sometimes not until June. The thick erect axis bears clusters of flowers below, single flowers at the top. Each cluster contains (1) male flowers, with stamens but no pistil; (2) complete flowers, of which some are really female, since the stamens fall off before the anthers open; (3) flower-buds, which do not open but wither and fall off.

Each flower is stalked, stands out horizontally, and is irregular (*zygomorphic*); there are five united green sepals forming a bell-shaped calyx, four free petals (an upper pair and a lower pair, sometimes with a fifth odd petal below). Each petal is white, with a yellow blotch (larger in the two upper petals) which later turns red, and jagged edges. Within the petals there is a ring-like nectary, thickest at the upper

side of the flower, and within this the stamens (usually seven) are inserted. Each stamen has a long filament which turns up at the end and bears a red anther. The pistil has a three-chambered ovary (two ovules in each chamber) and a long pointed style bearing stigmatic hairs.

The flowers are visited by insects, especially bees. In a perfect flower the style is ready to receive pollen before the anthers open. When a bee visits a newly opened flower the style, which projects forwards and upwards, touches the bee's abdomen, while the unripe stamens are bent down. Later the stamens ripen and turn forwards and upwards, so that the anthers are brought into the position formerly occupied by the style. Cross-pollination is further aided by the fact that the male flowers in an inflorescence are the first to open, also by the presence of the "female" flowers, *i.e.* those whose anthers fall off without having opened.

The ovary grows into a brown globular spiny fruit (a *capsule*, though differing from most capsules in having a rather fleshy wall), which opens (about October) by three valves and usually contains two seeds (see Art. 98).

†Some varieties of Horse Chestnut have "double" flowers, with structures intermediate between petals and stamens. The Buckeye Horse Chestnut (*A. pavia* or *Pavia rubra*) is a small tree (up to 20 ft.), with five stalked leaflets to each leaf, dull (not sticky) buds, small flowers, and smooth fruits. The Red Horse Chestnut (*A. rubicunda*) has very dark-green leaflets, dark-red flowers, and spiny capsules, but the leaflets are (as in the Buckeye) spindle-like in outline, though not stalked.

310. Common Lilac (*Syringa vulgaris*), a native of Persia and Central Europe (introduced into Britain about 1600), forms a shrub or small tree (up to 20 feet), which grows rapidly (as much as a yard per year for the first three or four years), but does not last very long—about 20 years in rich soils, but 40 or 50 in dry poor soils (why this difference in duration?); it is well known for its handsome appearance when in leaf and its abundant and beautiful flowers. It sends up suckers profusely in all directions; why do gardeners clear these away as they appear, when a fine tree is desired?

The leaf has a long stalk; the blade, usually heart-shaped but rather variable in outline, is thin and has its surface

smooth and its edge entire. The leaves are in crossed pairs. The buds are large and green; the bud-scales are smooth and green, in crossed pairs. As a rule the end-bud has either died off or produced an inflorescence, so that the end of a twig usually has two buds side by side. The buds are somewhat sunk in the base of the leaf-stalk in whose axil it stands, and each has four or five pairs of hard scales, then about ten pairs of young leaves which just touch each other at the edges, so that the bud is a very easy one to dissect. Some of the buds contain only leaves, others (larger) both leaves and an inflorescence.

The flowers (blue, purple, red, or white, in different varieties) are in large loose clusters, the main axis bearing groups of stalked flowers on its branches. The calyx is short and four-lobed; the corolla has the same general shape as that of a Primrose, consisting of a long trumpet-like tube and four horizontal lobes. There are two stamens inserted by short filaments on the inner surface of the corolla-tube. The ovary is two-chambered, the style long and ending in two small stigmas. Besides being fragrant, the flowers have honey, produced at the bottom of the tube; they are visited by bees and butterflies. The capsule opens by two valves; the calyx is persistent.

† Besides the Common Lilac several other species are grown in Britain, e.g. **Persian Lilac** (*S. persica*), introduced in 1840, with purple flowers (in some varieties white), small lance-shaped leaves (in some varieties lobed deeply), a small shrub (4 to 6 feet); **Josika's Lilac** (*S. josikaea*), about as large as Common Lilac, but with leaves broadly lance-shaped, wrinkled, short-stalked, and white below, introduced in 1835, flowers purple, but the corolla-lobes not spread out; and the **Rouen Lilac** (*S. rothomagensis*), a hybrid between Common and Persian with intermediate characters, a shrub about 7 feet high.

All the Lilacs are propagated by the suckers; good seeds are not usually formed unless the suckers are mostly cut away and the bunches of flowers thinned out (why?). They can all be grafted on the Ash, which belongs to the same family (Oleaceae).

311. Common Ash (*Fraxinus excelsior*) is a fairly tall tree, often 80 feet high; it is a native of Britain, but has generally been planted. It is easily distinguished by its stout grey twigs, usually turned up at the ends, its compound leaves in crossed pairs, and its stumpy black buds, also by its characteristic "keys" (Fig. 121).

Note that the base of each leaf runs down on the stem as a projecting cushion, so that the stem is flattened below each pair of leaves; this gives the twigs a knotted appearance when the leaves have fallen. The leaves have about five pairs of side-leaflets and an end-leaflet; the leaflets are stalkless, narrow, pointed, and slightly toothed.

The buds have 4 to 6 pairs of scales, of which only the outermost ones (2 to 4 scales) are visible on the outside; these outer scales are covered with black hairs. When the bud opens, one generally sees transitions between the bud-scales and the foliage-leaves. The large end-buds grow into leafy shoots, but in April, before the leaves appear, clusters of flowers grow out from the side-buds.



Fig. 121.—The Ash, with a Cluster of Fruits.

The inflorescence shows the same branching as in Lilac; the main axis gives off branches which branch again, and the last branches end in flowers. The flowers may be either male, female, or perfect; the three kinds may be present on the same tree or on separate trees, being grouped in various ways. There are always two stamens in a male or perfect flower (filaments joined below in male flower), while the pistil is bottle-shaped and consists of a two-chambered ovary, tapering style, and two stigmas. The flowers are mostly wind-pollinated, though sometimes visited by insects.

The fruits are winged akenes (samaras); the long and often twisted wing is formed from the top of the ovary and shows at first the remains of style and stigmas on its tip. Note the thickened basal part of the key, forming a cavity which contains the single long flat seed. When the seed germinates (Art. 102), the whole key is carried up; the cotyledons remain inside it at first to absorb the food stored in the endosperm, then come out and form oval green leaves. The first foliage-leaves are three-lobed, but not compound.

In the Manna Ash (*Fraxinus ornus*) of South Europe the flowers have sepals and petals, so that the Common Ash has evidently lost these parts through becoming wind-pollinated. Other plants belonging to the Olive family are Privet (native) and various introduced plants—e.g. Lilac, Jasmines, Forsythia, Olive.

QUESTIONS ON CHAPTER XIX.

1. How would you distinguish an Elm *in winter* from a Beech, a Lime, or a Sycamore?
2. Describe the leaves and flowers of the Common Elm, and compare with those of the Wych Elm.
3. Describe the fruits of Common Elm and Wych Elm, with sketches. How are Elm fruits dispersed? At what time of year do they ripen?
4. How is the Common Elm chiefly propagated, and how does it differ in this respect from the Wych Elm?
5. Describe all the external features seen on a Sycamore twig showing several years' growth. Give sketches, and explain all the marks and structures you have drawn.
6. Describe the flowers of Sycamore, and compare with those of Hedge Maple. Give sketches.
7. Describe the fruits of Sycamore, and compare with those of Maple. How can you distinguish between Sycamore and the true Plane-tree (a) in winter by bark and buds, (b) in summer by leaves and flowers?
8. Describe the leaves of Horse Chestnut, and compare with those of Sycamore. Give sketches to show the relation between the two types of leaf.
9. Describe the flowers of Horse Chestnut, and compare with those of Sycamore. Note the adaptations for pollination.
10. Describe the fruit of Horse Chestnut, and compare it with that of Sweet Chestnut. How may the latter plant be distinguished by its leaves and flowers?
11. Compare the external features of the shoot (excluding flowers and fruits) of Sycamore and Horse Chestnut.
12. Describe the mode of growth and the external features of the Lilac. How is the Lilac usually propagated in gardens?
13. Describe the flowers and fruits of Lilac, with sketches.
14. Describe the winter features of the Common Ash. What other common trees resemble it in some respects (state these), and how can the Ash be distinguished from them?
15. Describe the leaves and buds of the Ash, with sketches. What distinctive features are shown by the twigs?
16. Describe the flowers and fruits of Ash, with sketches, and mention the adaptations for pollination and for dispersal.

CHAPTER XX.

PINES, LARCH, FIRS, YEW, JUNIPER.

312. Scots Pine or "**Scotch Fir**" (*Pinus sylvestris*) is usually easy to distinguish from other Pines by the bluish-green foliage-leaves ("needles") arranged in pairs; the bark, orange-coloured except at base of trunk, where it is dark; the pointed cone, with a dull surface.

The tree rarely exceeds a hundred feet in height. In plantations or forests it shows a tall branchless stem (any signs of branches formerly present?) with an umbrella-like crown, but in the open it keeps the lower branches for many years. The bark on the upper part of the trunk peels off in thin scales, leaving the surface orange-coloured, but near the base the scales remain attached for a long time, so that the bark here is thicker, rougher, and darker. The structure of the buds, their mode of expansion, and the growth of the branches, have already been dealt with (Art. 194).

The stiff needle-like foliage-leaves are borne in pairs, each pair on a short or dwarf-shoot. Each leaf is slightly twisted; the upper side is flat, the lower curved, and the two sharp edges bear small teeth (how can one perceive these without using a lens?). The leaves live for three or four years, their duration depending on the amount of light they receive. Each dwarf-shoot bears about a dozen small scales, forming a sort of sheath at the base of the two needles. The whole dwarf-shoot is cast off when the leaves are dead, giving the old twigs a rough scarred surface.

Each year a circle of long-shoots is formed, so that the age of the tree (after the first three years of its life) can be told at once from the number of these circles of branches, or

their remains if they have broken off. When the end-shoot is damaged, one (sometimes more) of the side-shoots grows out so as to replace it; in fact, one sometimes finds that one of the side-buds does not expand along with the others, but remains as an "emergency-bud."

The flowers (May, June) are of very simple structure; the male and female flowers are on the same tree. The male flowers (Fig. 122) are yellow egg-shaped bodies, about $\frac{1}{4}$ inch



Fig. 122.—The Pine, showing Cones.
(Sketch made in June.)

long; they represent dwarf-shoots, and are crowded together at the bases of the year's long-shoots. Each male flower is in the axil of a scale, and has about four scales at its base; it consists of a slender axis bearing numerous spirally-arranged stamens. Each stamen has a very short filament and a scale-like anther with a small crest at the free end; on the lower side are two pollen-sacs which open by longitudinal slits and let out the dusty sulphur-like pollen. Shake a branch, or hit it with a stick, when the male

flowers are ripe. Each pollen-grain has two air-bladders, one at each side, which make the grain more buoyant by giving it a much larger surface without much extra weight.

The male flowers fall off after the pollen is shed, so that if the stem goes on producing male flowers year after year it shows a tufted arrangement of the needle-bearing dwarf-shoots, the tufts being separated by bare parts of stem which mark the former positions of the clusters of male flowers.

Each female flower or "cone" (Fig. 122) arises in the position of a lateral long-shoot. Its bud grows rapidly in the first year and is then nearly spherical (about $\frac{1}{4}$ inch long) and stands erect on a short stalk. At the base of the cone there are some small scales, and above these come the scale-like carpels. Each carpel consists of a lower scale bearing on its upper surface a larger and thicker scale; the latter has two ovules ("young seeds") on its upper

side near the base. While the pollen is being blown about, the axis of the cone lengthens so as to separate the scales and allow the pollen grains to reach the ovules. Then the stalk of the cone bends down, while the scales grow larger and thicker and become tightly packed together.

Next year the cone begins again to grow bigger and becomes egg-shaped and pointed (about 2 inches long). In the third year the cone dries up, the scales gape apart (starting at the top of the cone), and the seeds escape. Examine cones of different years. Do all the scales of a ripe cone bear seeds? How many seeds are on each scale? Note the long thin wing attached to the seed, enabling it to be carried far by the wind.

The early germination of the seed has already been described (Art. 105). After the cotyledons have absorbed the endosperm and escaped from the seed, long needle-like leaves are produced, which *stand singly and directly on the stem*. In the second year single needles are produced at first, but they gradually dwindle upwards into scales; in the axils of the upper scales there arise the two-leaved dwarf-shoots. Thus the young Pine resembles adult Firs in having the foliage-leaves borne singly and directly on the stem.

†**313.** Other species of Pine are often grown in Britain, and the commonest of these are fairly easy to distinguish from the Scots Pine. Of the kinds with two needles on each dwarf-shoot, the **Black** or **Austrian Pine** has larger cones, longer (up to 7 ins.) and darker green needles, darker and coarser bark; the **Stone** or **Umbrella Pine** has long (up to 7 ins.) but slender and bright green needles, larger and more rounded cones (about 5 × 4 ins.); the **Cluster Pine** has still longer leaves (up to a foot), thick and fleshy, cones in clusters of six or often more, long egg-shaped (up to 8 ins. long). The **Weymouth Pine** has its needles in *fives* on the dwarf-shoots, each needle about ½ ins. long, cones curved and about 5 ins. long.

314. Larch (*Larix europaea*) is easily recognised by the numerous short thick dwarf-shoots, very conspicuous in winter when the tufted leaves have fallen (Larch differs from most other Conifers in *not* being evergreen). See Art. 195.

The tree rarely exceeds ninety feet in height, and the main branches, which are not arranged in regular circles as in Pine, spread out at first horizontally from the trunk, or bend down, but turn up at the ends, while the finer branches mostly hang downwards. The Larch is a light-demanding tree, and has a

tapering crown ; the lower branches die much sooner than in Pines when the trees are closely planted.

The foliage-leaves (about 1 in. long) are soft, flat, light green, with a ridge along the lower side and a blunt tip. Those on the long-shoots are arranged singly and are more pointed, while those on the dwarf-shoots are crowded to form tufts (20 to 60 in a tuft) and are longer and narrower (Fig. 123). In autumn the needles turn brown and fall off.



Fig. 123.—The Larch,
with Cones.

The male (yellow) and female (red) flowers, which occur on the same tree and open in spring, arise from buds (resembling vegetative buds) on the ends of the dwarf-shoots. The male flowers are solitary, but otherwise resemble those of Pine in general structure; the pollen grains have no air-bladders. The female flower has below it a tuft of needles (none are formed below the male flower) which gradually pass above into the scales at the base of the flower itself. It is always erect or nearly

so; if the branch itself is not erect, the stalk of the female flower curves so as to bring the flower into the right position. Its structure is essentially the same as in Pines, except that the scales which bear the seeds are at first much smaller than the red lower scales (bracts), the latter being alone visible from outside. However, after fertilisation the bracts wither while the seed-scales grow actively, close up, and become woody (but not thick as in Pine).

The cone ripens in the first year and is egg-like (1 to 1½ ins. long); it opens in the following spring, but the old cones remain on the tree for many years. The seeds are winged but small; the seedling during the first few years of its growth is evergreen, the upper leaves at least remaining on the plant during winter.

†315. The only relatives of the Larch are the **Cedars**, the three kinds of which are all planted for ornament in Britain—Cedar of Lebanon, Deodar, Atlantic Cedar. The Cedars resemble the Larch in general structure, especially in having

numerous needles in the tufts on the dwarf-shoots, but the needles are *evergreen* (lasting for three to five years) and rigid (why?), besides being darker green; the male flowers are larger (about 2 ins. long), the cones larger (about 3 ins. long) with short broad thin scales.

†**316.** In the many other Conifers grown in Britain there are only long shoots, on which the foliage-leaves are directly borne. In the **Spruce Fir** (*Picea excelsa*), a tall tapering tree with branches in circles and the horizontal twigs tending strongly to be arranged in two lateral rows, the leaves are four-angled and narrow, the cones are cylindrical (about 5 ins. long) and fall off as a whole. In the **Silver Fir** (*Abies pectinata*) the leaves are flat, and on the finer twigs they have a curious appearance, as if combed out to form two series, one on each side of the twig, lying in the horizontal plane, owing to the twisting of the upper and lower leaves; the leaves have a silvery appearance, the cones are erect, the bracts have long tips which project beyond the seed-scales, and the scales fall off separately and leave the cone-axis bare. The **Douglas Fir** (*Pseudotsuga douglasii*) agrees with Silver Fir in some respects (leaves flat, bracts project beyond seed-scales), but with Spruce in others (leaves not spread out on flanks of twigs, cones pendant, scales fall off).

†**317. Native British Conifers.**—Many other Conifers are cultivated in this country (Monkey's Puzzle, Cypressess, etc.), but the only native (*i.e.* not introduced in historic times) plants of this division are the Scots Pine, Yew, and Juniper.

The **Yew** is an evergreen tree with a massive trunk and spreading branches. The narrow, dark green leaves are glossy above, slightly curved, and are thickly set on opposite sides of the branches. The male and female flowers are produced on separate trees, on the under side of the twigs. The male flower consists of a scaly bud with a tuft of stamens (each umbrella-like, with about six pollen-sacs) projecting above its summit; the female flower does not produce a cone, but somewhat resembles a small acorn (up to $\frac{1}{2}$ inch long) in form, and develops into a red cup-like "fruit," containing a small "nut," the top of which is exposed. The "nut" is, of course, the seed; the cup is an extra seed-coat (*aril*).

The **Juniper**, a bush with crowded narrow prickly leaves in whorls of three, about an inch long, also has its male and female flowers on separate plants, in axils of leaves. The male flower has the stamens in 4 or 5 whorls (3 stamens in a whorl); each stamen has 3 pollen-sacs; the female flower (small, bud-like, green) has a few scales surrounding a whorl of three erect ovules. The black fleshy "berry," ripe in the autumn of the second year, is about $\frac{1}{2}$ inch long, nearly globular, and the fleshy part is formed by the scales around the seeds themselves.

QUESTIONS ON CHAPTER XX.

1. Describe the appearance of a twig of Scots Pine examined in winter. Give sketches.
2. Describe a Pine twig as seen in May or June. What is observed if the twig is shaken at this time?
3. Make a careful sketch showing the various parts seen at the end of a Pine twig in June :—male flowers, young dwarf-shoots, and young cones.
4. Why does a Pine branch show whorls of branches? Why is there often a bare piece of stem just above each of these whorls?
5. Describe the various structures which may arise from the resting-buds of the Pine.
6. For how long may the foliage-leaves (needles) remain on a Pine tree? What other leaf-structures are found on a Pine shoot?
7. Describe the structure of a male flower of Pine, with sketches.
8. Describe the appearance and structure of a Pine cone at different stages (first year, second year, third year, etc.), with sketches.
9. How are the seeds of the Pine dispersed? What other plants have *seeds* provided with a similar dispersal mechanism?
10. How could you distinguish a Larch from a Pine (*a*) in winter, (*b*) in summer?
11. Describe the general appearance of a Larch twig, with sketches, and compare it with a Pine twig.
12. Describe the male and female inflorescences of Larch, with sketches, and compare with those of Pine.
13. How do Pines and Larches differ from Firs and most other Conifers?
14. Describe the seedling of a Pine, showing how the adult arrangement of the leaves is acquired.
15. Describe the leaves, flowers, and fruits of Yew and Juniper, and point out their peculiarities.

CHAPTER XXI.

THE ECOLOGY OF PLANTS.

318. Plant Ecology.—Having now gained some practical knowledge of the structure and life-processes of plants, you should proceed to study the vegetation of your own district and that of any district you may visit. The main object of this study should be to find out as much as possible about the various ways in which plants are influenced by, and adapted to, their surroundings or “environment.” The term **Plant Ecology** simply means “the study of plants in their homes.” Much can be done in this direction even with limited knowledge of the classification of plants; but the more you know of structure, physiology, and classification, the better will you be equipped for the study of plants from the ecological point of view. It is an easy task to learn how to distinguish the commoner plants, especially those which show striking adaptations to some special locality or “habitat.”

There are various books which enable one to identify any flowering plant met with in this country. The most complete of these “Floras” are Bentham and Hooker’s *British Flora* and Hooker’s *Student’s Flora*; the former is illustrated, and is the more expensive of the two. Smaller books, less complete and less expensive, are Hayward’s *Pocket Flora* and Watts’s *School Flora*. A still cheaper, but extremely useful, Flora is Fox’s *How to find and name Wild Flowers* (Cassell, 1s. 6d.), which may be recommended to beginners in the work of plant identification. *Plant Biology* (Clive, 3/6) contains a summary of the chief Orders (Appendix III.), together with monthly lists of plants in flower (Appendix IV.).

319. Terms used in Plant Ecology.—We have already seen that various plants grow together in certain localities—

e.g. in water or in marshes (Ch. VIII.), on moors and in bogs (Ch. XI.)—evidently because they “like” or “prefer” (that is, are adapted to) the same kind of soil, the same conditions of dryness or wetness, the same amount of light or of shade, etc. Such groups of plants, growing together in a sort of community, may be called Plant Associations.

There are four main groups of Plant Associations. At one extreme we have plants adapted to life in ponds, rivers, ditches, growing partly or entirely submerged in water. These true water-plants are said to be *hydrophilous* (*i.e.* “water-loving”), and are termed **Hydrophytes**. Plants which grow in marshes or swampy ground, on river-banks or on ditch-sides, are said to be *hygrophilous* (“moisture-loving”) plants, or **Hygrophytes**.

At the other extreme we have plants which are adapted for life under conditions of “physiological” drought—that is, under such conditions that it is necessary to check or greatly reduce the rate of transpiration, or to store up water, or to do both, because the water supply is scanty or runs through the soil too quickly for the roots to absorb much of it, or because the water cannot be absorbed freely on account of the presence of excessive amounts of dissolved salts or of peaty matter, or because the plant grows in places exposed to high drying winds, or in cold soil, or exposed to excessive light. A little reflection will show that any of these causes will lead to the development of adaptations for reducing transpiration or for storing the scanty or precarious supply of water which the plant can absorb. In other words, such plants will be *xerophilous* (“drought-loving”) plants, or **Xerophytes**. Xerophytes occur on heaths and moors, also in the boggy places which accompany them; on high mountains with an Alpine flora; in sandy localities; on chalk downs; on the sea coast (cliffs, rocks, sandy beaches, sand-dunes, salt-marshes); and in woods or plantations of Pines, Firs, Larches, and other Conifers.

Between xerophytes and hygrophytes we find a great many intermediate forms (**Mesophytes**), comprising, in fact, the majority of British plants, which grow in meadows, pastures, cultivated fields, and in woods and plantations of deciduous trees (Beech, Oak, Birch, etc.). These plants show no decided xerophilous or hygrophilous characters, though some approach

xerophytes in form and structure and others approach hygrophytes.

Woody perennials (trees and shrubs) with deciduous leaves show distinctly xerophilous characters in winter (the protected winter buds, cork-covering of stems and of leaf-scars, cork-layer closing up the lenticels), while in summer they bear thin leaves like those of mesophytes or hygrophytes. It has been proposed to call such plants, which are more or less hygrophilous in summer and xerophilous in winter, **Tropophytes** (i.e. "changing plants"). This applies only to deciduous plants; evergreen land-plants are more or less strongly xerophilous in character, their leaves being usually tough, thick, and leathery (e.g. Holly), or needle-like (e.g. Pine), and possess thick cuticle, sunken stomates, and other xerophilous features.

It must be remembered that no hard-and-fast lines can be drawn between these types. For instance, some aquatic plants can, when the stream or pond dries up, continue to live and grow, sometimes even more vigorously, in the air, thus changing from hygrophytes to mesophytes. The same species of plant may be found growing under hygrophilous or xerophilous conditions in different localities. In each case the structure of stem and leaf, as well as the form of the leaves and the general habit of the plant, become modified to suit these different modes of life. Coast-plants like Samphire (*Crithmum*) or Sea-plantain can be grown in ordinary soil, and develop thin instead of fleshy leaves.

320. The Geographical Distribution of Plants.—We have already seen that a certain temperature, a supply of oxygen, water, and carbon dioxide, an appropriate substratum and exposure to light, are all essential conditions for the growth of green plants. In every case the plant can only grow when these essential conditions are fulfilled, and the intensity, concentration, or amount of each such factor must not fall below, or rise above, certain limits. For example, there is a certain optimal supply of water, carbon dioxide, light, etc., at which growth is most rapid, while below the minimal or above the maximal amounts it rapidly or gradually ceases. In some cases—as, for example, in the case of submerged water-plants—the optimal supply of water is also the

maximal, and, in fact, the position of these three cardinal points for each factor differs greatly according to the plant examined.

Usually, however, the minimal and maximal points lie fairly wide apart, so that the same plant which grows best under a special set of conditions may be able to prolong a more or less enfeebled existence when these conditions have undergone more or less modification in one direction or the other. Some *cosmopolitan* plants indeed possess such pronounced powers of adaptation that they are able to exist in almost every part of the globe. Certain factors, such as light, moisture, and soil, influence more especially the local distribution of plants, whereas others, such as temperature, and in some cases moisture, also determine the general or geographical distribution of plants over wide areas.

The possible range of any given plant is in all cases determined by the character and mode of life of the plant itself, and by its powers of accommodation and distribution. By slightly changing the former the plant may be able to progress from one zone to another if its seeds are widely dispersed, and the offspring, by adapting themselves to the altered conditions in the new zone, may ultimately come to diverge widely from the parent species. The local distribution of plants is often due to the fact that the seedlings are only able to withstand the stress of competition with other plants when the conditions are specially favourable to them or unfavourable to their competitors.

We are, of course, chiefly concerned here with the local distribution of plants; but, before proceeding to study the vegetation of our own country, it is well to gain some information about the general distribution of plants, which will help us to understand more fully the conditions on which plant-distribution depends.

The distribution of plants on the earth's surface is dependent upon (1) the environment, (2) the powers of dispersal, (3) the existence of barriers to migration, (4) the distribution of plants in the past.

321. Environment.—In the study of Plant Biology you should always be on the alert to ascertain whether the differences in form and structure presented by different plants can

be accounted for by differences in their mode of life and habitat. This study requires a sound practical knowledge of the morphology and physiology of plants. All the factors that make up the environment must also be taken into account. These factors fall into two main groups: (1) the **climatic** factors, including temperature, rainfall, light; (2) the **edaphic** factors, including the physical and chemical characters of the substratum—*i.e.* in most cases the soil. The environment includes not only the non-living, but also the living surroundings. The former include (a) temperature, (b) moisture, (c) light, (d) soil or other medium; the latter include (e) other plants, (f) animals, (g) man.

322. The Temperature influences all plant functions to a pronounced extent. Growth, cell-division, carbon-assimilation, and life-processes in general, all decrease as the temperature falls and cease in most plants at or about 0°C . They take place most actively at from 20°C . to 30°C . in most cases, and usually cease above 40°C . to 45°C ., although a few Bacteria and Algae are accustomed to the much higher temperatures of certain hot springs, where Algae play an important part in the formation of "sinter" or "travertine" deposits. Respiration, on the other hand, may continue feebly even below the freezing-point of water, and increases steadily as the temperature rises until the plant or cell is killed.

Transpiration is also accelerated by high temperatures, and diminished by low ones, provided that the stomata remain open, and that the air is correspondingly saturated with water-vapour in both cases. In hot *moist* air, however, transpiration may be less active than in fairly cold but *dry* air.

On the whole, most plants prefer temperatures lying between 20°C . and 30°C ., although many are specialised to withstand very high or very low temperatures.

323. Moisture.—Within the Tropics dry and wet seasons alternate in regular succession, farther north and south comes an almost rainless zone, and in the temperate regions we have variable winds and rain. These three regions are characterised by plants which differ as regards the amount of moisture they require. Thus in the Tropics a great abundance of *hygrophilous* (moisture-loving) plants is found which can only exist under moist conditions, while in the dry regions mainly *xerophilous* plants are found, which require but little water, and can survive prolonged periods of drought. The plants of temperate regions lie mostly between these two extremes.

Hygrophilous plants are usually of large size and luxuriant, devoid of prickles or thorns, and with an abundance of stomata and a thin cuticle. Most Ferns and Palms, Bananas, etc., are hygrophilous. Xerophilous plants have either succulent or very hard shoots, either

no leaves or fleshy or leathery ones, or phyllodes as in *Acacia*. Hairs, scales, glands, prickles, and thorns are commonly present. The cuticle is thick and often covered with wax. Tuberos roots or shoots are common, and the main stem is often underground. Cactuses are typical xerophytes, and so also are very many *Acacias* and *Euphorbias*.

324. Light determines mainly very local distribution, some plants loving the shade (Wood-sorrel, Cow-wheat, Yellow Dead-Nettle, Moschatel, and Sweet Violet) and others full exposure to the sun (Poppies, Stonecrop, Sun Spurge).

325. The Substratum, taking this term in the widest sense, also determines very local distribution. Many plants grow only in bogs and swamps, others in peaty soils or in **humus**, i.e. soil rich in vegetable remains, others in running or stagnant water, others on sandy or muddy coasts. Similarly some plants prefer chalky soils, others rich loam, while some succeed in maintaining themselves on the poor thin soil derived from granite rocks.

It must be remembered that plants grow largely where animals or other plants will let them, and hence a plant may inhabit a poor soil not from choice, but from necessity.

The influence of man is mainly displayed in cultivated plants, some of which have been traced back to the Stone Age.

326. Other Factors in Distribution.—The dispersal of seeds and fruits by wind, water, and animals, as well as by movements of the plants themselves, has already been discussed (Ch. VI.). The chief barriers to migration are deserts, saline tracts, seas, rivers, lakes, and mountains. The influence of the *past distribution* of plants is often very great, and this, together with the existence of barriers to migration, is responsible for the fact that similar but widely separated regions may contain very dissimilar floras. Plants never occupy all the areas suitable to them. For example, several British weeds introduced into Australia and North America have found there a suitable soil and climate, and hence have spread rapidly, although they might never have reached these continents but for the agency of man.

327. Humus Plants.—Some of these simply prefer the humus as a medium on which to grow. Others, however, use the humus as a source of food. They are aided in this by the presence of symbiotic fungi (mycorrhiza) on their roots, which absorb and digest the humus, handing over all or a portion of it in a suitable form to the plant. Plants of this kind commonly have their foliage-leaves reduced to mere scales, as in the Bird's-Nest Orchid. When the leaves are fully developed, the mycorrhiza probably enables the plant to absorb nitrogen from the humus, and not carbon. Humus collects in most bogs and swamps, but here it is the water which is of primary importance in influencing distribution.

328. Chalk-Plants.—Of plants which prefer or are in some districts entirely restricted to calcareous soils, may be mentioned the wild Columbine, the Lily of the Valley, the Fly and Bee Orchids, Rock Rose, the Bloody Crane's-Bill (*Geranium sanguineum*), Stinking Hellebore (*Helleborus fetidus*), Traveller's Joy (*Clematis*), Yellow Gentian (*Chlora*), *Campanula glomerata*, Whitlow-grass (*Draba muralis*), Dyer's Weed (*Reseda lutea*), Wild Flax (*Linum perenne*), Dogwood (*Cornus*), Wayfaring Tree (*Viburnum lantana*), Mouse-ear Hawkweed (*Hieracium pilosella*), Privet (*Ligustrum*), Verbena, Deadly Nightshade (*Atropa*), Hound's Tongue (*Cynoglossum*), Pasque Flower (*Anemone pulsatilla*).

Chalk soils are usually dry, and, in dry continental climates, plants which grow in almost all soils in England may be unable to develop on the calcareous regions of the continent. Thus *Hypericum pulchrum*, *Stellaria holostea*, *Galium saxatile*, Birch, and Broom are all absent from the calcareous Jura mountains, but grow freely upon the Vosges, on which the soil is formed of decomposed granite, and also in marl soils in which the presence of some clay renders the soil more retentive of moisture.

329. Clay-Plants.—Pure clay does not form a soil preferred by any flowering plant, and is highly unsuitable to most. When dry the soil bakes hard, and is almost impenetrable by the roots, while the very fact that when moist it is highly retentive of water renders it difficult for the plant to absorb sufficient water unless the soil contains a large amount. In this case the soil is very badly aerated, and hence for lack of oxygen the roots are unable to develop to any great extent or to penetrate deeply. If mixed with sand, chalk, or humus, however, the soil is much improved, and many plants will survive periods of drought on such soils, whereas they may perish on more porous ones. Such plants as Lily of the Valley, Lesser Celandine, Wood Sanicle, Coltsfoot, Primrose and Cowslip, Bittersweet, Yellow Dead-Nettle, Garlic, Early Purple Orchid, Blue-bell, are found, in some districts at least, to prefer soils containing a good deal of clay.

330. Sand-Plants.—These include (a) those plants which prefer merely a sandy soil, and (b) those of the sea-coast (**strand-plants**) which have adapted themselves to the presence of salt. Many such plants grow equally well in ordinary soil, but lose certain of their characteristics, and probably would not survive if left open to free competition. Practically all such plants have strongly xerophilous characters; for example, reduced leaf-surface, thick fleshy or prickly leaves and stems, stunted habit, thick cuticle, deeply sunk stomata, etc. Sand-plants, pure and simple, are often very prickly, thorny, or hairy, whereas hairs are usually absent or few in number on strand-plants.

As instances of sand-plants the following may be mentioned: Mousetail (*Myosurus*), Sand Spurrey (*Spergularia*), Stork's Bill (*Erodium*), Broom, Wormwood (*Artemisia*), Golden Rod (*Solidago*), Wood Sage (*Teucrium*).

331. Strand-Plants.—The plants which grow along our shores, either on sand or in mud-flats (salt-marshes), are sometimes called *Halophytes*, or saline-plants. They either prefer salty soil, or grow here because their competitors are more sensitive to salt and are unable to follow them. All strand-plants are more or less xerophilous in character, and this is also the case with regard to plants growing on salt-marshes or muddy shores. Here the plant strives to reduce its need of absorbing water to a minimum, so that it shall not absorb too much salt. Hence the plants are fleshy or leathery, the cuticle is thick, the stomata often sunken, and the leaf-surface often reduced or spiny. Since high winds often prevail, the flowers are usually small, and the seeds are rarely winged, but there are exceptions to both these rules; the Sea-poppy has large yellow flowers, and the Sea-thrift has a persistent membranous calyx, which forms a funnel-like wing on the fruit.

Coast-vegetation varies according to the nature of the soil; rocky shores, sand-banks or "dunes," and muddy salt-marshes have each their own typical plants, though there are often transitions from one to the other. On rocks and cliffs we find Sea-plantains (*Plantago maritima* with entire fleshy leaves, *P. coronopus* with lobed hairy leaves), Scurvy-grass (*Cochlearia*), Samphire (*Crithmum*, an Umbellifer, with lobed fleshy leaves), Sea-thrift (*Armeria*, with heads of pink flowers), Sea-campion (*Silene maritima*). Several of these plants (Thrift, Sea-campion, Scurvy-grass, and *Plantago maritima*) occur also on high hills inland, but not in the low-lying parts between the hills and the coast.

On sandy shores, close to the sea, we find such plants as Sea-poppy (*Glaucium luteum*, with large yellow flowers and very long fruits), Orache (*Atriplex*, several species, shrubs with mealy leaves and spikes of small green flowers), Sea-beet (with fleshy swollen tap-root), Sea-blite (*Suaeda*, with cylindrical fleshy leaves), Saltwort (*Salsola*, rather like Sea-blite, but with a spine at the tip of each leaf), Sea-convolvulus, Sea-holly (*Eryngium*, an Umbellifer with leaves like those of Holly, and small blue flowers in heads like those of Teazel), Sea-purslane (*Arenaria peploides*, with crowded decussate ovate fleshy leaves), Seakale (*Crambe*, with thick fleshy rhizome; leaves 6 ins. to 10 ins. long, stalked, broad, fleshy; flowers white, in corymbs), Sea-rocket (*Cakile*, like *Crambe*, but annual, leaves only 2 ins. to 3 ins. long), Sea-spurge (*Euphorbia paralias*, with woody rhizome, fleshy leaves, milky juice as in other Spurges), Sea-milkwort (*Glaux*, belonging to Primulaceae; a small fleshy plant with creeping rhizome, narrow leaves in pairs; flowers small, axillary, with white or pink calyx, no corolla, capsule opening by five valves). All these plants have either fleshy or leathery leaves, and are either annuals, or, if perennial, have long tap-roots or rhizomes by whose upward growth the plants keep above the surface and avoid being buried by the shifting sand.

Further back from the sea we come to sand-dunes in which grow various grasses and sedges. The most conspicuous grasses are the Marram-grass, Lyme-grass, Sea Barley, Sea Timothy, Sea Couch-grass (Art. 292). Along with these grasses, and farther inland, come the

Sand Sedge (*Carex arenaria*, whose rhizome burrows deeply in the sand, running in straight lines and sending up shoots bearing tufted leaves, which are therefore arranged in lines along the surface of the sand) and other plants, whose creeping stems and tufted roots bind the shifting sand and thus prepare firmer soil for other plants. Farther from the sea come such plants as Rest-harrow (*Ononis*), Bird's-foot Trefoil (*Lotus*), Bird's-foot (*Ornithopus*), Thyme, Stork's-bill, Stonecrop, Ling, Heather, etc.

332. Salt-Marshes or mud-flats occur chiefly near the mouth of a stream, usually not far from sand-dunes, and are most extensive in the tidal estuary of a river. The vegetation of a salt-marsh is quite distinct from that of sand-dunes, though a few plants occur in both sand and mud—e.g. Sea-milkwort, Sea-plaintains, Thrift, Scurvy-grass, *Suaeda*, *Salsola*. One of the most typical plants of salt-marshes is the Marsh Samphire or Glasswort (*Salicornia*), which has green or reddish cylindrical and fleshy branches, divided into joints, the leaves being represented only by small teeth at the joints, where also the very small flowers are produced. In the wettest parts of the salt-marsh, which are submerged at high tide, we find, along with *Salicornia*, a Monocotyledon called *Zostera*, with long narrow floating leaves.

Farther inland, out of reach of most tides, occur such plants as Sea-lavender (*Statice*, with woody creepy rhizome, "radical" lanceolate leaves, purple flowers in dense corymbose inflorescence), Thrift, Sea-milkwort, Sea-plaintain, Sea Arrow-grass (*Triglochin maritimum*, with long narrow fleshy leaves, long flowering shoot, leafless, and ending in a raceme of yellow-green flowers), Salt Spurrey (*Spergularia*, belonging to Caryophyllaceae; narrow fleshy leaves with scaly stipules, flowers pink), Sea-daisy (*Aster tripolium*, like the Michaelmas Daisy of gardens, but with fleshy leaves), Golden Samphire (*Inula crithmoides*, a Composite, with a stout and rarely branched stem, 6 ins. to 18 ins. long, covered with narrow entire or slightly lobed fleshy leaves; flower-heads yellow, in a small corymb).

333. Plants and their Habitats.—Look for all these plants in their homes or "habitats," and note any others that occur along with them. Notice especially the conditions under which plants live in streams, ponds, marshes, bogs, heaths, chalk downs or limestone hills, sandy soils inland, and on rocky, sandy, and muddy shores, and the various ways in which the plants you find in such localities are adapted to their surroundings. Sketch the plants, find out the orders they belong to and their specific names, and make sections of the vegetative parts (stems and leaves especially) to see how they differ in structure according to the conditions and surroundings in which they grow. Try experiments which may help you to understand better how

plants become adapted to special conditions of life. For example, dig up plants found on the coast, and compare the effect of watering these plants and ordinary herbaceous garden-plants with a solution of common salt or of Tidman's Sea Salt (about a handful to two quarts of water).

Even if you cannot visit the coast or the moors, there is ample scope for study in woods and plantations, hedges and ditches, streams, ponds, and marshes.

334. Woods and Plantations.—In your study of woods and plantations, notice, in addition to the trees, the undergrowth of Shrubs Brambles, Bracken-fern, and of smaller plants, and, in regard to the latter, find out the order in which the different plants spring up and flower. The same ground, in a wood not too densely shaded by the trees, bears at different times of the year such plants as Wood Anemone, Blue-bell (Wild Hyacinth), Dog's Mercury, Wood Spurge, Primroses, etc. Many of these woodland plants only grow in shaded places—*e.g.* Wood-sorrel, Cow-wheat, Bird's-nest Orchid, Yellow Dead-nettle.

335. Hedges.—Many shade-plants grow in hedgerows, the flora of which presents several interesting features. At the top of a hedge-bank the light is very feeble and the soil dry. Now all plants which grow in dry soils require plenty of light, so that the only plants which can develop at the top of the hedge-bank are either plants with long erect stems, such as the Hedge-mustard, Nettle or Thistle, or climbing plants such as *Convolvulus*, Hop, Clematis, Goosegrass. Lower down the hedge-bank, where there is more moisture and light, a great variety of plants may develop, while in the shady ditch beneath we may find at the sides Cuckoo-pint (*Arum maculatum*), Ladies'-smock (*Cardamine pratensis*), etc., and in the water of the ditch the Water-buttercup, Water-cress, Duckweed, and other aquatic or amphibious plants.

Certain plants such as Poppies and Sun Spurges cannot survive under a shady hedge. Others such as the Garlic, Adoxa, Violet, grow well by fairly damp hedgerows. Others again, such as *Erodium*, *Geranium*, etc., will grow well on the sides of dry hedgerows provided they are freely exposed to light.

The hedge itself most commonly consists of Hawthorn, but often of Gorse, Bramble, Sloe, or of small trees like Willow or Hazel. These have usually been planted, as have, of course, the hedges consisting of shrubs like Laurels, Privet, Rhododendron, etc., around parks and plantations. Why do hedges need to be pruned or "cut back," and what is the effect of this operation? Notice that plants like Dead-nettles, Yellow Toadflax, Campions, Stitchwort, when growing close to the hawthorn (or other shrub forming the hedge) push up between the branches and have long weak stems, although the same species, when growing some distance from the hedge, have short erect stems with closely arranged leaves. Cases like these suggest the way in which plants, originally erect and self-supporting, may have become climbers through lack of light and the presence of a suitable support.

It is very interesting to compare the nature and general appearance or "habit" of the plants growing along the north and south sides of a hedge which runs east and west. The south side is, of course, warmer, drier, and receives more light, and various plants grow on this side that either do not grow at all on the north side, or are found there in smaller numbers and showing less luxuriant growth. In the same way the trunk of a tree which is growing in an open situation (*i.e.* not among others in a damp wood) generally has its moister side (which?) covered with a green powdery Alga (*Pleurococcus*, which is so common on trunks and palings) and with various Mosses, Liverworts, and Lichens, while the drier south side is usually quite bare. In a damp wood the trunks and branches of the trees are often thickly covered with these "epiphytic" plants, often also bearing Ferns (especially Polypody).

In highly cultivated countries the hedgerows form one of the most important refuges of the original wild plants which covered the country before the advent of the plough. The other chief refuges are by the sides of streams, in stony waste places, and in permanent pastures. In many cases a plant may be able to accommodate itself to very varied surroundings, and such plants have naturally more chance of surviving. Ephemerals, and rapidly seeding annuals, such as the Chickweed, Groundsel, and Field Veronica, may long survive even on well-cultivated arable land, since their seeds may ripen and fall in the intervals between successive weedings.

336. Adaptation.—We have already considered some of the adaptations of form and structure which are shown by plants growing in certain habitats (moors, salt marshes, etc.), but a little reflection will show that *every* plant must, in order to hold its own in the struggle for existence, be more or less completely adapted to its surroundings—in other words, every plant growing in its natural habit must be sufficiently well equipped to survive in the competition for light, air, etc., which is continually going on between it and other plants of the same and of different species.

This struggle for existence is naturally keenest in those localities in which the soil is fairly rich in plant-food, and which receive sufficient moisture, warmth, air, and light. It is easy to see why far more plants belonging to different species grow in open fields and roadsides, along hedge-banks and ditches, than in shaded woods and plantations, on moors or in salt-marshes. Mesophytes far outnumber the more extreme types adapted to special habitats in which the struggle for existence is less severe. On the other hand, specialisation usually entails a loss of adaptability—*i.e.* a loss on the part of the plant of the power of accommodating

itself to new surroundings. Hence highly specialised plants must usually conquer their surroundings in order to survive, and remain as "fixed" types as long as they can do this, but become extinct when subjected to adverse conditions.

337. The Plant's Equipment.—We have seen that the plant body is a machine made up of different parts performing different functions, and thus showing more or less well-marked division of labour. In studying the adaptation of plants to the external conditions in which they live, one is apt to concentrate attention on the special advantages possessed by certain plants and to neglect the great majority of plants which seem to show no striking biological adaptations.

A little observation and reflection will, however, convince one that what counts in the struggle for existence is the whole equipment of the plant, not the possession of any single adaptive or advantageous feature. For instance, plants provided with specially good mechanisms for seed-dispersal are often apparently no more successful or widely distributed than allied plants which have not these particular mechanisms. Daisy and Milfoil (Yarrow) are two of the commonest plants in this country, though they are comparatively poorly equipped as regards seed-dispersal, since they differ from most British Composites in having no pappus. The same applies to other isolated advantageous characters possessed by certain plants, and not by other plants which are closely allied, or found in the same habitat, or equally successful as judged by their abundance and wide distribution.

338. An acquaintance with plants in their habitats teaches us that the formation and development of hairs, spines, and prickles depend to a great extent on external conditions. Thus the same plant that produces these parts when growing in a poor, dry soil fully exposed to the rays of the sun, becomes of a much softer and less aggressive character when grown in a rich, moist soil. Under the former circumstances the plant not only protects itself from herbivorous animals, but also, by converting some of its buds and leaves into spines, reduces the amount of its foliage, and thus economises its scanty supply of water. Many succulent plants, however, which grow in dry situations, such as the Stone-crop (*Sedum*) or the House-leek (*Sempervivum*), show but little or no tendency to form hairs, prickles, or spines since they have other means of checking transpiration (thick cuticle, etc.). The Rest-harrow (*Ononis arvensis*) has no spines when grown in rich, moist soil, but in dry, exposed situations the great majority of the branches end in hard, sharp points.

The hairs present on the stem are always cutinised, and when this is very pronounced they become almost impermeable to water. In such cases, especially when the hairs die at an early stage of the development of the leaf or stem bearing them, they may serve to protect the plant, and especially the young growing organs, from an excessive loss of water. Hairs, when thickly set, help to cut off

sensitive growing organs from excessive illumination, which retards their growth and may injuriously affect them. Similarly, a close covering of hairs is of some importance in retaining heat during the night and thus keeping the plant warm, while hairs are also of great value in preventing the surface of the plant from being wetted by rain.

Why are the leaves of most shade-preferring plants (*e.g.* Enchanter's Nightshade, Wood Anemone, Sanicle, Moschatel) devoid of hairs and more delicate in texture than those of plants growing in open situations? Why are the leaves of many plants growing in exposed places provided with a covering of hairs? On which side of the leaf is the hairy covering developed most, and why? Why are evergreen leaves (*i.e.* leaves which remain on the plant for two or more years) usually tough and leathery, with thick cuticle, a relatively small amount of air-space in the mesophyll, sunken stomata (few in number, and confined to the lower surface as a rule), and other xerophilous characters?

339. Field Observations.—It cannot be too strongly insisted upon, that outdoor observations are absolutely essential in studying the distribution of plants and their adaptations to environment. To study this branch of Botany, *i.e.* Plant Ecology, with success it is necessary to have a good general knowledge of British flowering-plants, which can only be acquired by collecting and identifying, as far as possible, all the plants met with. At first attention may be confined to the commoner plants and to those which show well-marked adaptations to their environment, and which occur chiefly in sharply defined "plant associations," *e.g.* water-plants, heath-plants, coast-plants.

The student cannot do better than begin field observations on some definite and fairly uniform area (*e.g.* a sea-shore; pond, marsh, river-bank; heath, common, moor; meadow, cultivated field or garden with its weeds, hedgerow, wood or plantation with its trees and undergrowth, etc.). Study this area at all times of the year, identify as many of the plants as possible, and keep a careful record, with sketches, of your observations. The following hints will suggest the main lines on which the inquiry should be conducted; others will occur as your field-work progresses.

1. Physical and climatic features of the area under observation (*e.g.* chemical and physical nature of the soil; whether retentive and ill drained or porous and well drained; height above sea-level; exposure to, or shelter from, light and wind, etc.).

2. List of the most abundant plants in the area, with notes (and sketches) on the following points in each case: General habit and mode of life (whether annual, perennial, erect, creeping, climbing, xerophytic, aquatic, saprophytic, parasitic, etc.); size, form, texture, etc., of leaves; structure of flowers, with special reference to mode of pollination; structure of fruits, with special reference to mode of seed-dispersal, quantity of seed produced, etc.

3. Reasons why certain species are present in the area under consideration and absent from neighbouring areas, and *vice versâ*. To determine these, compare the physical features of the different areas, and try to map out the whole district into regions characterised by definite plant associations, which will, of course, be found to merge into one another at their edges.

It need hardly be added that the subject of Plant Distribution cannot be mastered by merely committing to memory lists of plant-names. It must be approached in the spirit of observation and inquiry, and the problems it presents answered with reference to the student's knowledge of the Structure and Physiology of Plants.

340. The Herbaceous "Type."--You should carefully compare the different parts of the plants which are studied as "types." A grass, a Dicotyledonous herb (e.g. Broad Bean), and a tree might be studied to begin with; the erect herbaceous type may be taken first, and the other types compared with it.

We have already compared in some detail the foliage-leaf and the cotyledon of the Broad Bean. You should draw up, in parallel columns, a comparison between the root and the stem, with reference to external form, colour, mode of branching, organisation of growing-point, position and arrangement of conducting and strengthening tissues, relative positions of wood and bast, position of first-formed vessels (protoxylem) in the wood, mode of secondary thickening, nature of response to gravity, light, moisture, and any other points that occur to you. Then try to discover, not merely by reasoning, but by observation and experiment, what biological advantage to the plant is derived from each of the differences noted.

341. The Grass "Type."--Grasses (see Ch. XVI.) are social or gregarious plants, which often cover large areas to the almost entire exclusion of other plants, and greatly exceed all other plant-families as regards number of individuals. They are adapted for existence in many kinds of habitat—running water (*Glyceria*, etc.), sand dunes (*Psamma. Elymus*, etc.), moors (*Nardus*, etc.). It is fairly easy to understand

why Grasses are such dominant and aggressive plants. Their seeds in most cases germinate quickly, and at a low temperature; the pointed shoot, enclosed by its sheath, can grow up to the air and light even when other plants are crowded in the spot where the Grass seed has fallen, while the numerous thread-like roots secure a hold even in the thinnest and poorest soil.

Most Grasses are perennial, and their rhizomes either creep onwards or branch freely, but remain short; in the latter case the plant is tufted. The rhizome sends up erect shoots which bear foliage-leaves, and usually end in an inflorescence. In most Grasses the "nodes" are more or less swollen, but as a rule this is due to thickening of the lower part of the leaf-sheath and not to thickening of the stem itself. The "nodes" consist largely of soft parenchyma whose cells are capable of growth, and when a shoot is laid in a horizontal position the "nodes" curve so as to bring the tip of the shoot into the erect position. The "ligule" present in most Grasses may serve to prevent rain-water from entering the leaf-sheath, but this is doubtful. The flowers are carried well above the vegetative region of the plant; this is an obvious aid in wind-pollination.

342. The Arborescent Type.—We have already studied the characters of **shrubs** and **trees**. There is, of course, no sharp distinction between shrubs and trees; various plants which form large trees when growing in sheltered or low-lying places are reduced to stunted shrubs when they occur on high mountains or wind-swept ridges. On Dartmoor, for instance, there are several patches of gnarled and stunted Oak trees, doubtless of great age, growing among granite boulders along river-valleys, at a height of about 1,500 feet. On several "tors" (granite-caps on hills) there grow Rowan (Mountain Ash) plants reduced to low-creeping shrubs a few inches high; in one case the flat top of a tor, about 1,800 feet above sea-level, was covered with this dwarf Rowan. Pines and Birches are also reduced to low shrubs on very high hills and in high latitudes.

343. Conclusion.—The student who has worked through the course of instruction outlined in this book, and has followed up the suggestions thrown out with regard to personal observations and experiments, should have gained a fairly sound and well-balanced knowledge of the Biology of Plants. There are many points concerning which our knowledge is incomplete, and many problems which await solution. This is especially the case with regard to plant-adaptations, which one is often too prone to generalise about from limited observations. The external and internal factors which control the morphology and physiology of plants are not always obvious or easy to unravel.

QUESTIONS ON CHAPTER XXI.

1. Distinguish between a species, a variety, a natural order, and a genus, illustrating your answer by reference to three examples of each. Can you exhibit the relations of the four in a diagrammatic form?

2. Name the three commonest English species of Buttercup. Describe any one of them as fully as possible, and point out exactly the characters in which the other two differ from it and from one another. Do you find them growing in similar or in different places?

3. Describe the chief modes of perennation in herbaceous plants.

4. For what different purposes do you consider that a plant requires to be supplied with water? How are some plants able to withstand long-continued drought uninjured? Give instances of such plants.

5. How does the climate inside a greenhouse differ from that without?

Name plants whose natural habitats are in climates (*a*) drier, (*b*) wetter, (*c*) hotter, (*d*) colder than that of an English garden. What arrangements would you make if you had to try to grow these various plants in England?

6. The island of Singapore produces more than 2,000 native species of flowering plants; the Isle of Wight (about equal in area) some 800; an equal area in the Egyptian Desert less than 200. To what causes would you attribute these striking differences?

7. Mention the six most troublesome weeds in any garden with which you are well acquainted. Explain carefully, so far as you can, the reasons why each is specially troublesome.

8. Mention any observations you may have made on the flora of ground that has been turned over but not planted—*e.g.* railway embankments, fallow fields, garden beds. Can you give a list of plants growing in such places, and account for their presence?

9. Give several examples of groups of plants which grow together in the same habitat or locality and flower at about the same season. Why do these plants grow side by side, what causes bind them to special localities, and why do they flower simultaneously?

10. Suppose you were asked to write a report on the vegetation of some particular acre of ground (heath, common, meadow, marsh, woodland, moor, or hillside), how would you set about the task? What would you try particularly to find out? What observations and notes would you make? How much time would you wish to be allowed for the inquiry?

11. Show, by reference to alpine plants, to the carpet of spring flowers in woodlands, to flowers of foreign origin in English gardens, to the lack of flowers in hayfields after July, and by other illustrations, that the competition of neighbouring plants is one important condition of plant-life.

12. Name several different species of plants that you have found at the seaside and not inland. State exactly where and how each was growing, and mention any characters possessed by each that you think fitted it to its particular circumstances.
13. Give an account of the vegetation of sand-dunes in any region you may select, and point out the special adaptations exhibited by the plants to their surroundings.
14. Write a list of plants which you have found on moorland walks. What peculiarities of leaf-structure have you observed in any six of these? How does the possession of such peculiarities profit the plant? What was the nature of the soil on which the moorland plants grew?
15. What wild flowers have you found growing along the margins of lakes, ponds, and rivers? Distinguish those which grow with their stems (a) wholly in the air, (b) partly in air and partly in water, (c) wholly submerged. Show by sketches what you mean by the zones of vegetation along the water margin.
16. Write a list of any plants which you have found growing with their leaves submerged in water. How do such plants obtain the gases which they require for respiration and photosynthesis? Describe the surface structure of a leaf (a) in a land-plant, (b) in a water-plant.
17. Write an account of the vegetation you might expect to find growing on a swampy moor, and indicate any points in which the plants appear to be structurally adapted to such an environment.
18. Name three English trees with which you are thoroughly familiar. Describe the habit, branching, buds, bark, leaves, flowers, and fruit of each. In what sort of situation would you expect to find each growing? Make your descriptions so clear that the trees could be easily distinguished and identified.
19. What special anatomical peculiarities would you expect to find in water-plants? Explain how the structure you describe is connected with their conditions of life.
20. Enumerate the more common plants which you have found growing in a marsh.

INDEX.

The numbers refer to pages. The detailed Table of Contents at the beginning of the book may also be consulted.

- Absciss-layer, 99.
Acer, 327.
Aconitum (Monkshood), 147, 148.
Acorn, 44, 177.
Adaptation, 351.
Agrimony, 177, 229.
Agropyrum, 303.
Agrostis, 304.
Air, Composition of, 25; concerned in Starch-making, 67; required for germination, 25; -spaces. 6, 84, 122, 214.
Aira, 305.
Akene, 45, 170.
Akenial Fruits, 170.
Alder, 176, 313.
Almond, 171.
Alopecurus, 303.
Andrecium, 148.
Anemone, 157, 173, 176.
Annual Rings, 118.
Anther, 148.
Anthoxanthum, 304.
Apocarpous Pistil, 150.
Apple, 171, 229.
Arborescent (Arboreous) Plants. 115.
Aril, 179.
Armeria, 348.
Arrhenatherum, 304.
Arrowhead, 176.
Arum, 94, 159.
Ash-tree, 54, 175, 179, 332.
Aspen, 309.
Avena, 297, 305.
Avens, 177, 229.
Awn, 297.
Bacteria, 23, 204.
"Balance of Nature," 81.
Balsam, 178.
Banana, 174.
Barberry, 149.
Bark, 121.
Barley, 177, 303.
Barren Strawberry, 225.
Bast, 117.
Bedstraw, 96.
Beech, 321.
Beetles, 157.
Begonia, 130.
Bellis (Daisy), 270.
Bent-grass, 304.
Berry, 171.
Biennials, 115.
Bignonia, 175.
Bilberry, 171, 246.
Birch, 170, 175, 317.
Bird's-foot Trefoil, 192, 201.
Bittersweet, 171, 261.
Blackthorn, 227.
"Bloom" on Leaves, 8, 99.
Bluebell, 150, 283.
Bog-plants, 247.
Bogs, 249.
Bombus, 162.
Bombylius, 158.
Bougainvillea, 176.
Brachypodium, 304.
Bramble, 173, 229.

- Briza*, 303, 304.
Bromus, 305.
 Broom, 188, 199, 201, 203.
 Brussels Sprout, 128, 130.
 Bryony, Black, 94; White, 262.
 Buds, 9.
 Bulb, 277, 284.
 Bulbil, 210.
 Bulrush, 176.
 Burdock, 177.
 Buttercup, 150, 170, 175, 210.
 Butterflies, 162, 237.

 Cabbage, 99.
Callitriche, 69.
Calluna, 244.
Caltha, 213.
 Calyx, 10, 146.
 Cambium, 120.
Campanula, 175.
 Capillarity, 23, 24.
 Capitulum, 152.
 Capsule, 169.
 Carbohydrates, 34.
 Carbon-assimilation, 70.
 Carbon Dioxide, 25, 27, 67.
 Carrot, 130, 177.
 Castor-oil Plant, 36; 54, 179.
 Catkin, 152.
 Cedar, 338.
 Celandine, Little, 146, 208.
 Cellulose, 33, 34, 54.
 Chalk-plants, 347.
 Cherry, 229.
 Chickweed, 150.
 Chlorophyll, 65, 70.
 Christmas Rose, 147, 148, 173.
 Cinquefoil, 225.
 Classification, 218.
 Cleavers, 262.
 Cleistogamous Flowers, 234, 239.
Clematis, 94, 176, 217.
 Clinostat, 103.
 Clover, Red, 192.
 „ „, White, 188, 192.
 Cobalt-papers, 87.
 Cock's-foot Grass, 304.
 Coco-nut, 171.
 Cohort, 218.
Colchicum, 200.

 Coltsfoot, 98, 272.
 Columbine, 217.
 Compositae, 176, 273.
Conifers, 339.
Convolvulus, 194.
 Cork, 121.
 Corm, 278.
 Corolla, 10, 147.
Corylus, 148, 314.
 Corymb, 152.
 Cotton-grass, 176.
 Cotyledons, 14, 33, 50, 56, 61.
 Couch-grass, 293, 303.
 Cowslip, 253.
Crataegus, 225.
 Cress, 53.
Crithmum, 343.
Crocus, 192, 276.
 Cross-pollination, 144, 153.
 Crowberry, 247.
 Crowfoot, 211.
 Cymes, 152.
Cynosurus, 304.
 Cytase, 54.

Dactylis, 304.
 Daffodil, 151, 284.
 Daisy, 96, 97, 147, 270.
 Dandelion, 147, 176, 265.
 Daphne, 291.
 Date, 54, 171, 174.
 Dead-nettle, 97, 147.
 Deliquescent Tree-form, 184.
Deutzia, 175.
 Diastase, 37, 67.
 Dicotyledons, 56.
 Digestion, 37.
Digraphis, 304.
 Dispersal of Seeds, 174.
 Distribution of Plants, 343.
 Dock, 176.
 Dog-rose, 221.
 Dog-violet, 232.
 Dogwood, 171.
 Drupe, 170.
 Drying-apparatus, 22.
 Duckweed, 60.

 Ecology, 341.
 Edaphic, 345.

- Egg-cell, 143.
 Elder, 171.
 Elm, 170, 175, 325.
Elodea, 69.
Elymus, 304.
 Embryo, 15.
 Enchanter's Nightshade, 177.
 Endosperm, 50, 53.
 Environment, 344.
 Epidermis, 82.
Epilobium, 175.
Erica, 245.
Eriophorum, 176.
 Essential Elements, 74.
 Etiolin, 71.
 Evening Primrose, 163.
 Evergreen Plants, 98.
 Excurrent Tree-form, 184.

Fagus, 321.
 False Acacia, 93, 197.
 Ferments (enzymes), 37.
 Fertilisation, 142.
 Fescue-grass, 305.
Festuca, 305.
 Fig, 173.
 Firs, 339.
 Flower Mechanism, 203, 236.
 Follicle, 169.
 Formaldehyde, 70.
 Foxglove, 115, 152.
 Foxtail-grass, 303.
Fragaria, 224.
Fraxinus, 332.
 Freesia, 291.
 French Bean, 43.
 Furze, 178, 188, 193.

Galium, 262.
 Geotropism, 109.
Geranium, 173, 178.
 Germination, 18, 31.
 " -boxes, 19.
 " -jars, 19.
 Glumes, 295.
 Gluten, 35, 36.
Glyceria, 304.
 Goat's-beard, 176.
 Gooseberry, 171.
 Goosegrass, 96, 177, 262.

 Gorse, 178, 188, 198.
 Grasses, 298.
 Grass of Parnassus, 160.
 Groundsel, 155.
 Gynecium, 149.

 Habitat, 182, 349.
 Hairs, 352.
 Halophytes, 348.
 Harebell, 175.
 Hawthorn, 172, 225.
 Hazel, 148, 314.
 Heart's-ease (Pansy), 236.
 Heartwood, 119.
 Heather (= Ling), 192, 199, 244.
 Heath-grasses, 299.
 " -plants, 247.
 Heaths (*Erica*), 199, 245.
Hedera, 240.
 Hedges, 350.
 Heterostyled Flowers, 155.
Holcus, 304.
 Holly, 171.
 Homogamous Flowers, 156.
 "Honesty," 175.
 Honeysuckle, 173.
 Hop, 173, 175, 194.
Hordeum, 303.
 Hornbeam, 175.
 Horse Chestnut, 53, 97, 129, 133,
 170, 177, 329.
 Hound's-tongue, 177.
 Hover-flies, 158.
 Humble-bees, 162.
 Humus-plants, 346.
 Hyacinth, Garden, 284.
 " , Wild (= Bluebell), 283.
 Hydrophytes, 342.
 Hygrophytes, 342.

 Inflorescences, 151.
 Insects, Flower-visiting, 156.
 Inulin, 34.
Iris, 175.
 Ivy, 200, 240.

 Jasmine, 291.
 Juniper, 339.

 Knots, 120.

- Laburnum*, 201, 202, 204.
 Lady's-fingers, 204.
 Larch, 184, 337.
 Larkspur, 217.
Lathyrus, 186.
 " , Functions of, 90.
 Leaf-arrangement, 7, 96.
 " -fall, 99.
 " -mosaics, 97.
 " -shapes, 92.
 " -structure, 81.
 Leguminosae, 203.
 Lens-work, 2.
 Lenticels, 122.
 Light, 31, 63.
 Lilac, 331.
 Lime-tree, 175.
 Ling (= Heather) 192, 199, 244.
 Linseed, 53.
 Lipase, 39.
 Lodicule, 295.
Lolium, 303.
 Lomentum, 172.
 Lucerne, 204.

 Maize, 48.
 Mallow, 172.
 Maple, 172, 175, 327.
 Mare's-tail, 96.
 Marsh Marigold, 173, 213.
 " Plants, 214.
 Marvel of Peru, 176.
 Mat-grass, 303.
 Meadow Rue, 217.
 Medick, 177.
 Medlar, 229.
Melica, 304.
 Mercury, Dog's, 166.
 Mesophyll, 83.
 Mesophytes, 342.
 Micropyle, 14.
Milium, 304.
 Milkwort, 149.
Molinia, 304.
 Moll's Experiment, 68.
 Monkshood, 173, 217.
 Monocotyledons, 56, 219
 Moorland Plants, 247.
 Moors, 247.
 Moth-flowers, 162.

 Mountain Ash, 227.
 Mulberry, 173, 177.
 Mustard, 53.

 Narcissus, 285.
Nardus, 303.
 Nasturtium, Garden, 53.
 Nitrates, 76.
 Nitrogen, 26.
 " , Fixation of, 205.
 Nitrogenous substances, 76.
 Nut, 170.
 Nutmeg, 179.

 Oak, 44, 135, 319.
 Oat, 297.
 Oat-grass, 297.
 Oils, 36; Digestion of, 39; in
 Trees, 119.
 Onion, 55, 284, 285.
 Orange, 171.
 Orchids, 174, 175, 285.
 Osier, 311.
 Osmosis, 23, 24.
 Osmotic Pressure, 25.
 Ovary, 149.
 Ovule, 142.
 Oxygen, 25, 69.

 Panicle, 297.
 Pansy, 179, 231.
 Papilionaceae, 203.
 Pappus, 170.
Parnassia, 160.
 Pasque-flower, 176, 217.
 Pea, Everlasting, 185.
 " Garden, 187.
 " Sweet, 184.
 Perennial Plants, 115.
 Pericarp, 168.
 Petiole, 8, 94.
 Petty Whin, 203.
Phleum, 303.
 Photosynthesis, 70.
Phragmites, 304.
 Pimpernel, 170.
 Pine, 55, 136, 141, 175, 335.
 Pistil, 11.
 Plant Associations, 342.
 Plantain, 96, 97, 152, 170.

- Plumule, 15.
Poa, 304.
 Pod, 12.
 Pollen, 11; -sacs, 11.
 " -tube, 143.
 Pollination, 141; Cross-, 144;
 Self-, 144.
 Pollinia, 287.
 Pome, 171.
 Poplar, 175, 179, 307.
 Poppy, 146, 170, 175, 222. ~.
 Potato, 149, 257.
Potentilla, 225.
 Prickles, 221.
 Primrose, 150, 251.
Primula, 251.
 Protandrous Flowers, 225.
 Proteids, 35; Digestion of, 38;
 Formation of, 77.
 Protogynous Flowers, 225.
Prunus, 229.
Psamma, 303.
Pyrus, 227.

 Quaking-grass, 304.
Quercus, 319.
 Quince, 172, 229.

 Raceme, 9.
 Radicle, 15.
 Radish, 53, 172.
 Ranunculaceae, 217.
Ranunculus, 210.
 Raspberry, 227.
 Rays in Wood, 119.
 Respiration, 27, 78.
 Robinia, 197.
 Rock-rose, 222.
 Root, 4-6, 59.
 Root-cap, 5, 112.
 " -hairs, 5, 89.
 " -nodules, 6, 204.
 " -pressure, 90.
 " -tip, 5, 108, 111.
 " -tuber, 208, 289.
 Rootlets, 4.
 Rosaceae, 228.
 Roses, 173.
 Rowan (Mountain Ash), 172, 227.
 Rye, 187.

Sainfoin, 204.
 St. John's Wort, 223.
 Salad Burnet, 229.
Salix, 307.
 Sallow, 312.
 Salt-marshes, 349.
 Samara, 170.
 Sand-plants, 347.
 Sanicle, 177.
 Sapwood, 119.
 Saxifrage, 150.
 Scarlet Runner, 193.
 Schizocarps, 172.
Scilla, 283.
 Scotch Fir (Scots Pine), 335.
 Seaside Plants, 348.
 Seed, 13.
 Sensitive Plant, 93.
 Shepherd's Purse, 143.
 Shoot, 6, 61.
 Shrubs, 183.
 Silicula, 169.
 Siliqua, 169.
 Silverweed, 225.
 Sketches, 2, 183.
 Sleep Movements, 190.
 Sloe, 227.
 Soil, 76.
Solanum, 262.
 Sorrel, Wood, 237.
 Spadix, 152.
 Spearwort, 211.
 Species, 218.
 Spectrum, 71.
 Spike, 152.
 Spines, 198, 226.
 Spring-flowering Plants, 290.
 Spring-wood, 118.
 Spurge, 173, 178, 179,
 Stamens, 11. -
 Starch, 34; Digestion of, 37, 66
 formed in leaves, 63.
 Stem, 2, 6, 61, 102, 112, 118.
 Stipules, 8, 93.
 Stitchwort, 175.
 Stomates, 7, 65, 82.
 Strand-plants, 348.
 Strawberry, 147, 173, 177, 224.
 Sugar, 34.
 Sunflower, 47, 96.

- Sweet Briar, 223.
 Sweet Pea, 9, 44.
 „ Violet, 232.
 Sycamore, 46, 172, 175, 179, 201, 327.
 Symbiosis, 205.
 Syncarpous Pistil, 150.

Tamus, 262.
Taraxacum, 265.
 Tare, 187.
Tarus, 339.
 Teasel, 176, 177, 227.
 Tendril, 8.
 Thrift, 176.
 Timothy-grass, 303.
 Tomato, 171.
 Tormentil, 225.
 Transpiration, 84.
 „ -current, 85, 87.
 Transport of food, 41.
 Traveller's Joy (see *Clematis*).
Trifolium, 188.
Triticum, 293.
Tropaeolum, 53, 94, 99.
 Tropophytes, 343.
 Trypsin, 38.
 Tuber, Root-, 208.
 „ , Stem-, 257.
 Tulip, 143, 150, 151.
 Turgescence (turgidity), 90.
Tussilago, 272.

Ulex, 198.
Ulmus, 325.
 Umbel, 241.
 Umbellifers, 175, 177

Vaccinium, 246.
 Valerian, 176.

 Variation, 218.
 Varieties, 218.
 Vegetable Marrow, 53.
 Veins, 94.
 Vernal-grass, 304.
 Vetches, 186, 187.
 Vetchling, 186.
Vicia, 188.
 Violet, 148, 150, 178, 231.

 Wallflower, 147, 175.
 Walnut, 171.
 Wasps, 161.
 Water, 22.
 „ Crowfoot, 212.
 „ -cultures, 74.
 „ Lily, 94, 146, 151, 176.
 „ Plantain, 176.
 „ -plants, 69, 214.
 „ Starwort, 65.
 „ Sweet-grass, 304.
 Wheat, 52, 293.
 Wheaten Flour, 35.
 Whin, 198.
 Willow, 175, 179, 310.
 „ -herb, 175.
 Wind-pollination, 154, 164.
 Winter Aconite, 148, 192, 217.
 Wood, 117-120.
 „ Anemone, 217.
 „ Sanicle, 177.
 „ Sorrel, 178, 192, 237.
 Woods, 350.

 Xerophytes, 342.

 Yellow Rattle, 175.
 Yew, 177, 179, 339.

Zostera, 349.





